Discrete Dynamics in Nature and Society

New Trends and Recent Advances in Operation Research on Supply Chains

Lead Guest Editor: Reza Lotfi
Guest Editors: Eren Özceylan and Gerhard-Wilhelm Weber

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Retraction

Retracted: The Nexus among Good E-Governance Practice, Decentralization, and Public Administration for Sustainable Local Development

Discrete Dynamics in Nature and Society

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] W. Balisany, H. Özgit, and H. Rjoub, "The Nexus among Good E-Governance Practice, Decentralization, and Public Administration for Sustainable Local Development," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 9886372, 11 pages, 2022.

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Retraction

Retracted: Environmental Regulation, Financial Resource Allocation, and Regional Green Technology Innovation Efficiency

Discrete Dynamics in Nature and Society

Received 15 August 2023; Accepted 15 August 2023; Published 16 August 2023

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[1] Q. Bao and H. Chai, "Environmental Regulation, Financial Resource Allocation, and Regional Green Technology Innovation Efficiency," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7415769, 11 pages, 2022.

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Research Article

Environmental Supply Chain Performance Mapping of an Enterprise by Exploring a Novel Vague-Intellectual Approach

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The authors notified the two momentous Research Gaps (RGs) via conducting the relevant literature survey. The authors found as first RG that there are still no mathematical models that could address the generalized trapezoidal fuzzy set (GTFs) based green supply chain performance measurement (GSCPM) multi-level hierarchical index for computing the performance of a production enterprise in % except in the forms of GTF set/scale/crisp value. Next, as the second research gap, the authors identified that a few research articles are published in the extent of degree of similarity approaches. Entire approaches are limited to recognize the weak metrics under assessment of two GTFN sets from experts and also not competent to measure the performance gap of metrics from its ideal value. The objective of research work is turned to overcome the identified two RGs. To fulfill the first RG, the authors first of all proposed the two GTFN set-based mathematical models, which are executed to compute the priority weights and appropriateness ratings (PWsaARs) for 1st level measures from 2nd level PWsaARs of metrics (discarded the requirement of PWsaARs data for 1st level measures from experts). Furthermore, the authors developed GTFN set-based novel fuzzy performance index (NFPI) approach (by combining the crisp as well as fuzzy percentage rule over FPI) to compute the performance in %. To address the second RG, the degree of similarity (DoS) approach is modified by introducing idea of negative and positive ideal solution into DoS (eliminate the need for assessment of two GTFN sets from experts). Next, modified DoS is applied over evaluated FPII (fuzzy performance importance index) to identify the weak and strong metrics and also quantify the GSCP gap of metrics from its ideal value. Eventually, the research work is demonstrated with empirical case research of an automobile parts manufacturing industry.

1. Introduction

Industrial sustainability (IS) issue has gained the momentum among performance's auditors and current researchers. Three pillars such as economic, social, and environmental are mostly contributing towards IS. Supply chain management (SCM) is found one of the significant operations, which is the heart and ought to be healthy plan and develop for each pillar to ensure the future sustainability of industries at competitive edge. SCM is defined a circuit, where factories, warehouses, distribution centers, retailers, and end users conclave for fulfilling their mutual needs and profits [1]. Among SCM, recently the green supply chain management (GSCM) strategy is ascertained as one of the sparking pillar of sustainability and received the amorous attention from global warming researchers. It is observed that methodical and tactical GSCM practices fruitfully participate in environmental pillar of sustainability and highly attempting towards developing the IS [2, 3]. In today's era, entire manufacturing sectors are highly provoked for utilizing the GSCM strategy to overcome the pollution as well as global warming issues, i.e., reduction of hot emission, avoidance of carbon contents, reuse the energies, recycling the wastes, and heat recovery to cope up with competitive edge [4–6].

GSCM is an introduction of green (environmental) thoughts into SC network, including the product design, material resourcing and selection, manufacturing processes, and delivery of the final goods to the consumers [7–9]. GSCM is a channel where creativity and innovations in SCM and industrial purchasing are brought under environmental concern [10–12]. GSCM is a dynamic decision support tool to address the ecological defies such as global warming, air and water pollution, and acid rains [13–17]. GSCM is the introductions of green trends in the bin of global supply chain in purpose to restore the earth's resources and build the world pollution free [18]. GSCM can be gained by augmenting the renewable energy processes, recycling of waste cum hazard materials, recycling of waste water, over processing, most excellent production, effective movement, elimination of manufacturing of defective products, and minimization of reworking [19–23].

It is found that the performance measurement (PM) is one of the decision support system and is explored to calibrate the performance and benchmark the industries based on scores [24, 25]. Sustainability PM tools are executed by SCM researchers cum global industries to map the overall performance under pillars of sustainability [26, 27]. To evaluate the GSCM performance scores, subjective and objective information is used for the modeling of the GSCM-based multihierarchical index consisting of performance measures and their metrics. However, authors sensed on peer-review of published research articles that comprehensive research documents are published focused on objective data modeling of the GSCM-based multihierarchical index in evaluating the permanence scores [28, 29]. Next, the authors found that most of the GSCM researchers [18, 30–32] attempted to develop a triangular fuzzy set-based GSCM hierarchical index (included general measures or limited to single level hierarchy) and able to evaluate GSCM performance score of alternative industries (except individual or single industry) [19, 33–40]. Next, the authors probed that a few researchers attempted to calculate GSCM performance in Triangular, GTFN set, and crisp value [37–39]. In extensive of the literature survey, the authors also found that short of the research work is conducted in degree of similarly (DoS) approaches, and the entire DoS approaches are used to only identify the weak and strong measures and metrics under assessment of two GTFN sets from experts [20–23, 41–47]. Therefore, the peer-review provided significant clues to authors to frame the pre-RGs and shared the contribution to overcome the RGs.

(i) The pre-research contributions are summarized as follows:

   (1) To identify and frame the GTFN set-based GSCPM multilevel hierarchical index, it consisted of the advanced crucial measure-metrics and accepted the green challenge of current contemporary industries.
   (2) To structure the GTFN-based new mathematical models, which could assess the GSC performance of a firm in percentage (%) under assessment of least GTFN information.
   (3) To identify the weak and strong metrics and also quantify the GSCP gap of metrics and measures from its ideal value. To potentially shape the entire (1)–(3) research contributions, the authors visited industries and conducted the comprehensive/secondary systematic relevant literature survey, which are discussed in Table 1 briefly.

2. Literature Survey

2.1. Research Gaps and Contribution

2.1.1. Research Gaps. In the last decade, the miscellaneous pollutants, i.e., ill-biological particles, fossil fuels, hazard particles, toxic gasses, undesirable flumes, and unwanted mono-carbon elements/stuffs/materials are more populated in environment due to rapid production rate with incompliance of the green (environmental) issues [84–86]. After conducting the comprehensive/secondary (in-depth) literature review, the authors re-notified and confirmed the same (1)–(3) research RGs, observed on peer-review stage, and discussed end of the Section 1. The confirmed (1)–(3) research RGs are discussed with rationales as follows:

(1) The previous researchers introduced GTFN set-based GSCM crucial measures and their interrelated metrics to build only a single-layer GSCM hierarchical index. There is an essential necessity to build the multilayers GSCM hierarchical index by introducing advanced-green technological focusing crucial measure-metrics.

(2) As per the evidence of previous research studies, the managers are not facilitated to compute GTFN set-based PWsaARs of 1st level measures by using the assigned PWsaARs information of metrics (2nd level hierarchy). There is an essential necessity to build the GTFN set-based mathematical models, where the managers can compute PWsaARs of 1st level measures by availing the evaluated PWsaARs of metrics (2nd level hierarchy).

(3) The previous researchers ensured the managers to compute the performance of firm in the terms of triangular/GTFN set or scale and crisp value. Therefore, the managers are not facilitated with GTFN set-based new approach for computing the evaluated GSCM performance in %. There is the imperative necessity to build GTFN set-based new approach to address this identified RG.

(4) The previous researchers proposed DoS approaches, which are executed to identify the only weak and strong metrics under assessment of two GTFN sets from experts. Therefore, the managers are not ensure

Table 1: Conducted comprehensive/secondary systematic relevance in the context of GSCPM strategy, GTFN mathematical models, and degree of similarly mapping between the GTFN sets.

The authors	Their research contribution in the context of GSCP strategy
[48]	Introduced a mixed-integer linear programming-based framework for designing the sustainable SC. The proposed framework is explored to evaluate the tradeoffs between economic and environmental objective in case study of a firm. The results showed that the current legislation and the emission trading scheme must be strengthened and harmonized in order to drive a meaningful environmental strategy.
[49]	Used statistics package-based software for establishing the structural modeling of proposed green hypotheses and helping to analyze the performance mapping of sustainable material providers.
[50]	Developed an interpretive structural modeling to display the effects of GSCM drive over the performance of case study of a firm.
[51]	Identified the essential green manufacturing practices to build a GSCM framework, which is used for solving the supplier election problem in the context of Indian manufacturing industry. The relationships between the green supplier selection practices are studied.
[52]	Developed a GSCM framework by conducting the relevant literature survey in the context of GSCM from 2000 to 2010. The developed GSCM framework is used for measuring the GSC performance of a firm.
[53]	Applied a fuzzy-TOPSIS (technique for order preference similar to ideal solution) approach upon GSCM framework (included GSCM practices) for ranking the twelve suppliers. The obtained results are computed by fuzzy-TOPSIS and next compared with the ranks obtained by both the geometric mean and the graded mean methods for selection of the final supplier.
[54]	Developed a multicriteria decision-making hierarchical model (consisted of the traditional as well as green criteria) and implemented it along with an intellectual approach to evaluate the best green supplier for a Singapore-based plastic manufacturing company.
[55]	The empirical data were collected from members of NAPM (North American Portability Management) to know their awareness and frequent applications of “green” purchasing in their firms. They all suggested that environmental factor is a crucial factor in the supplier evaluation problem. Lastly, green purchasing was suggested as a powerful factor to reduce and eliminate the waste.
[56]	Recognized the twelve behavioral factors such as top management support, performance appraisal and reward, communication, green training, and employee empowerment in the context of mining GSCM. An interpretive structural modeling (ISM) has been explored to setup the interrelationships among the identified behavioral factors.
[20]	Presented an efficient supplier performance assessment index with GTFN set. A fuzzy overall evaluation index is estimated towards assessing the GSC performance of alternative suppliers.
[57]	Displayed that environmental metrics are key factors for evaluating, selecting, and maintaining any supplier. Case study of an auto industry is carried out to justify this assertion.
[58]	Highlighted and suggested a few factors, which may be considered as the initiatives of GSCM.
[59]	Developed a meditational regression model and applied it to find out the effect of green practices upon their interrelated practices. The model results depicted that supplier must be evaluated with cost and fast delivery with environmental concerns.
[60]	Proposed a double layers GSC efficient appraisement model for benchmarking the green alternative suppliers. A triangular fuzzy set is used to handle the vagueness associated with supplier’s model and select the most significant supplier.
[61]	Investigated the GSC as retailer strategy. It is found that GSC aids the retailer to improve their retailing profit with low promotional efforts.
[62]	Determined during a case study of coal enterprise of China that various driving mechanisms, i.e., government regulations, enterprise resource capability, and supply chain aid the global industries to reach to the green innovation.

Table 1: Continued.

The authors	Their research contribution in the context of GSCP strategy
[63]	Developed a multiobjective decision making hierarchical model, which included the forward and reverse logistic practices. The model is used to optimize and reduce the recycling as well as manufacturing cost.
[64]	Investigated the benefits of the green innovation policy and pricing strategy for remanufacturing system of a firm. After investigation, green innovation policy and pricing strategy are applied in purpose to determine the competitive advantage of them.
[65]	Proposed a hierarchical evaluation model (consist of green performance parameters) towards evaluating as well as selecting the alternative green vendor.
[66]	Proposed a dynamic integrated model with platform ecosystem framework (consisted by formal taxonomy indicators) to find the interrelationships across formal taxonomy indicators of platform ecosystem.
[67]	Analyzed the impact of an effort cost coefficient of low-carbon product advertising across the dual-channel SC. It is found that sharing ratio of low-carbon product advertising effort cost impacts on the profit of a dual-channel SC
[68]	Applied the differential game theory investment strategy over vertical incentive scheme of manufacturing and retailing sectors to analyze benefit of cost subsidy.
[69]	Proposed a new decision support system (GSCM framework with grey-Delphi approach) and applied it for evaluating and selecting the best and weak criteria from various criteria. It is suggested to oil and gas industry to improve its performance for weak criteria.
[70]	Applied knowledge-based network for analyzing the impact of association among strategy, intellectual capital, and network and finance over organizational performance of Brazilian small- and medium-sized enterprise.
[71]	Applied the four techniques, i.e., statistics, machine learning, data mining, and optimization to map the GSCM performance of supplier organizations under internal environment management, green purchasing, customer green cooperation, and general criteria.
[72]	Proposed and applied a three-path group decision making technique with decision-theoretic rough set (DTRS) as well as hesitant fuzzy linguistic (HFL) to solve the green vendor evaluation and selection problem. The results explicated that proposed techniques can well handle the expert's assessment.
[73]	Built a judgment making decisional model to appraise the value of green suppliers under law and risk parameters. The proposed model enabled the organizations for managing the GSC. The authors extended research work with framing a new vague set-based approach for recognizing and predicting the relationships amongst the green supply risk parameters.
[74]	Conducted the relevant literature survey in the context of SCM and identified SC research areas, relationships among SC indicators, and emerging topics of SC.
[75]	Constructed the three pricing models and analyzed them simultaneously by changing the optimal profits of SC members and the optimal GSC degree of complementary products.
[76]	Identified the relationships among the green logistic operations, national economic, and environmental indicators and also ranked the best logistic countries over the period from 2007 to 2018.
[77]	Conducted the significant literature review on industry 4.0 SC strategies and identified and proposed the six research categories of industry 4.0 SC strategies with future research directions.
[78]	Recognized the vital relationship between the waste management practices and sustainability. The authors also evaluated the cause and effect relationship between them by using decision-making trial and evaluation laboratory (DEMATEL) approach.
[79]	Explored the qualitative survey to acquire in-depth knowledge by interviews against multisector organizations, which enable the authors to propose the areas where eco-innovation needs to be performed.
[80]	Proposed an integrated framework including digital project-driven supply chains (PDSC) indicators used to solve the multiple objective problems of architecture, engineering, construction, and operations and maintenance (AECOM) value chain.

Table 1: Continued.

The authors	Their research contribution in the context of GSCP strategy
[81]	Presented a summary of existing literature survey conducted over on machine learning (ML) in logistics and supply chain management (LSCM). It is concluded after analyzing the current literature, data, contemporary concepts, and gaps that suggested that LSCM must be intensified towards future researchers for research.
[82]	Audited the merged effect of internal environmental management (IEM) and green human resource management (GHRM) for corporate reputation (CR), environmental performance (EP), and financial performance (FP). The further indirect effects of CR and EP are analyzed.
[83]	Extracted the data from 76 commercial banks of four countries, i.e., Pakistan, India, Bangladesh, and Sri Lanka for the period 2009–2018. The generalized method of moments (GMM) is used to analyze the results. It is found that supply chain always encompasses the risk variables and is covered by qualitative assessment.
The authors	Their research works related to measure the degree of similarly between GTFN sets.
[33]	Proposed a novel fuzzy set-based intellectual technique to map the degree of similarity between the two generalized fuzzy sets. The similarity was measured from the center of gravity points of trapezoidal to triangular generalized fuzzy sets.
[34]	Measured the similarity between the two GTFN sets by merging the concept of left and right apex angles with center of gravity. The similarly between the two GTFN sets are mapped based on area, perimeter, and height.
[35]	Developed a new fuzzy based arithmetical approach considering the least number of parameters for computing the degree of similarity between the two GTFN sets.
[36]	Merged the idea of the predictable interval with dice similarity measure of two vectors for calculating the degree of similarity between the two GTFN sets.
[37]	Proposed a new degree of similarity concept, which measured the centers of gravity and the geometric distance between the two GTFN sets.
[38]	Proposed a multicriteria decision making appraisement model (consist of green-lean-agile logistic activities) with fuzzy performance index approach to assess the overall performance of a firm.
[39]	Identified that the domestic smog adversely impact the environment. The authors proposed a mathematical method to analyze this problem and provided the multiple solutions to minimize the smog pollutions.
[40]	Conducted the relevant literature survey in the extent of logistic 4.0 sustainability to overcome the vagueness of identified previous research gaps. The literature assisted the authors to propose a framework for measuring the logistic, sustainability, and technological adaptation of a warehouse.
[19]	Presented a framework consisted of 25 drivers linked with 8 criteria for analyzing the performance of a smart manufacturing firm. An integrated grey technique for order preference by similarity to ideal solution (Grey-TOPSIS) is implicated to rank the drivers. The obtained ranking is also validated using "complex proportional assessment or grey (COPRAS-G)" approach.

to trace that how much % of performance of each metrics need to be augmented to become 100% fit or meet idea value. There is a necessity to introduce the concept of ideal solution to void the assessment of the two set and measuring the GSCM performance gap of metrics from its ideal value.

2.1.2. Research Contributions. The RGs are transformed into research contributions (RCs). Figure 1 depicts the virtual picture of formulated problems/quotation of RCs. The entire RCs are framed as follows:

(1) The authors committed to build the measure-metrics based double-layer GTFN set-based GSCPM hierarchical index, addressing the green challenge of industry 4.0

(2) The authors committed to develop and propose the two GTFN set-based mathematical models, which could aid the managers to compute PWsaARs of 1st level measures from availing the evaluated PWsaARs of metrics (2nd level hierarchy)

(3) The authors dedicated to develop and propose a GTFN set-based novel fuzzy performance index (NFPI) approach to transform the GTFN set or scale into %

(4) The authors planned to modify the DoS approach by introducing an idea of negative and positive ideal solution into DoS, which ensure the managers to trace that how much % of performance does each metrics needs to become 100% fit to its meet ideal value

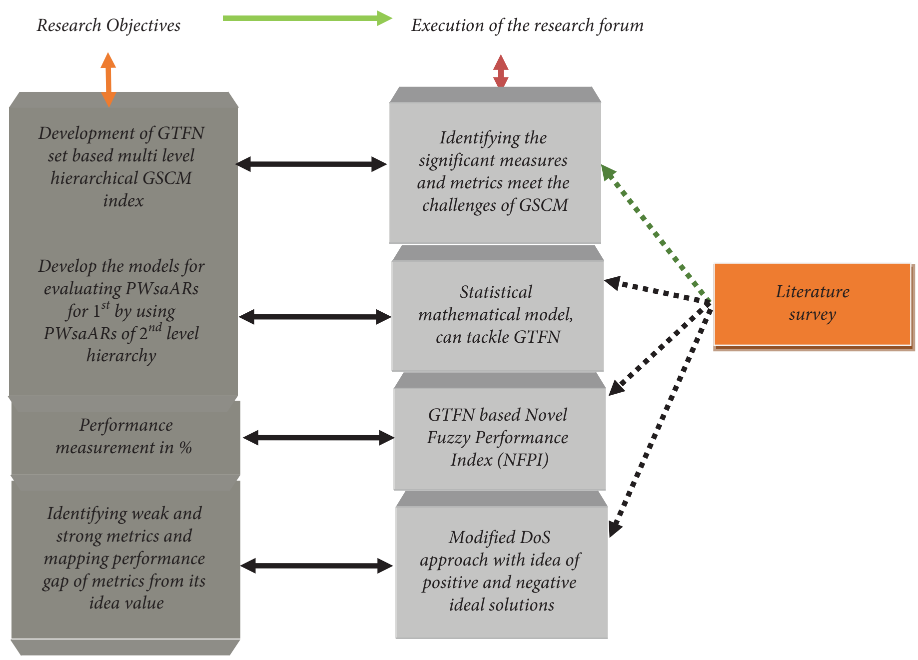

Figure 1: Problem formulation.

3. Fuzzy Logic and Set Theory

The fuzzy set theory was introduced by [87] in 1956 as well as [88] for addressing the problems associated with vagueness. It is considered as a mathematical tool for modeling the language and approximates the situations where fuzzy criteria exist [89]. In a universe of discourse X, a fuzzy subset A of X is defined by a membership function $f_A(x)$, where element (x) in universe of discourse X is represented by the real numbers in the closed interval $[0, 1]$. Here, the value of $f_A(x)$ for the fuzzy set A is called as the membership value or the grade of the membership. The membership value represents the degree of x belonging to the fuzzy set A [90–93]. The greater $f_A(x)$, the stronger the grade of membership for X in A. The linguistic value is used for approximate the reasoning within the framework of fuzzy set theory [87, 89, 94, 95] for handling an ambiguity, involved in linguistic expression, and normal trapezoid or triangular fuzzy numbers. We can define operations of fuzzy sets by using the extension principles [22, 60, 95–98].

Definition 1. Based on the extension principle, we can derive the arithmetic of fuzzy sets as shown in [87, 95, 97, 98].

A GTFN set can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, and the membership function $\mu_{\tilde{A}}(x)\colon R \longrightarrow [0,1]$ is expressed as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1} \times \tilde{\tilde{w}}_A, & x \in (a_1, a_2), \\ \tilde{\tilde{w}}_A, & x \in (a_2, a_3), \\ \dfrac{x - a_4}{a_3 - a_4} \times \tilde{\tilde{w}}_A, & x \in (a_3, a_4), \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty). \end{cases} \quad (1)$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $\tilde{\tilde{w}}_A \in (0, 1)$.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4;\, w_{\tilde{A}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4;\, w_{\tilde{B}})$ are two GTFN sets, then the operational rules of the GTFN set $\tilde{a}$ and $\tilde{b}$ are shown as follows as per reference [96, 97]:

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4;\, w_{\tilde{A}}) \oplus (b_1, b_2, b_3, b_4;\, w_{\tilde{B}}) = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{A}}, w_{\tilde{B}})), \quad (2)$$

$$\tilde{a} \ominus \tilde{b} = (a_1, a_2, a_3, a_4;\, w_{\tilde{A}}) - (b_1, b_2, b_3, b_4;\, w_{\tilde{B}}) = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{A}}, w_{\tilde{B}})), \quad (3)$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4;\, w_{\tilde{A}}) \otimes (b_1, b_2, b_3, b_4;\, w_{\tilde{B}}) = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4; \min(w_{\tilde{A}}, w_{\tilde{B}})), \quad (4)$$

$$\tilde{a} \phi \tilde{b} = (a_1, a_2, a_3, a_4;\, w_{\tilde{A}}) \phi (b_1, b_2, b_3, b_4;\, w_{\tilde{B}}) = (a_1 \div b_4, a_2 \div b_3, a_3 \div b_2, a_4 \div b_1; \min(w_{\tilde{A}}, w_{\tilde{B}})). \quad (5)$$

4. GTFN Set-Based Variant Approach Fuzzy Approach

The authors proposed the GTFN set-based variant approach, which included four sub-associated section of section 4. The aggregation of appropriateness ratings and priority importance weights is shown in 4.1. The Novel Fuzzy Performance Index (NFPI), for which the results are calculated in percentage (%), is shown in 4.2. The computation of fuzzy performance importance index (FPII) is displayed in 4.3, and the modified degree of similarity (DoS) mathematical model used for Identification of weak and strong performing GSC metrics is exhibited in 4.4. The chief objective of the proposed approach is to overcome the previous drawbacks of research works and fruitfully fulfill the identified RGs. The pros of the approach are that the proposed GTFN set-based variant approach is capable to tackle the subjective information of experts accurately and precisely. The assigned information in the terms of linguistic scale corresponding to GTFN sets is bounded by four values under membership function, which deliver the precise as well as true results. The approach is able to address all research objectives and contributions. The cons are that the approach is so complex in nature and difficult to understand [99–103]. The computation in decision evaluation problems by using this approach is comprehensive in nature as set included the four values under GTFN membership function.

4.1. Aggregation of Appropriateness Ratings (ARs) and Priority Weights (PWs). The priority weight (PW) reflects the importance, while rating reflects the value of measure/metrics as per subjective perception of DMs [104–106]. It is observed in many studies that PW influences the decision making scenario. The assigned priority weight corresponding to metrics can fruitfully change the preference order of performance metrics. The high PW is assigned to the most significant metrics [107]. We can understand by analyzing a scenario model of supplier evaluation, if the supplier's performance is evaluated based on the two metrics such as purchasing cost (PC) and service (S). In this case, DMs assigned the PW such as purchasing cost (PC) = 0.55 and service (S) = 0.45 under sum of PW = 1 and assigned the same rating such as PC = 50 and S = 50 (out of rating = 100 point). Then, it is found by calculating score that supplier = $W * R$(PC) = 0.55 * 50 = 27.50 and $W * R(S)$ = 0.45 * 50 = 22.5. It is explicated that assigned different weights against metrics under same ratings can change the preference order of metrics in measuring performance of a firm.

On the other hand, in the benchmarking decision making process or mapping performance of alternative industries, assigned ratings by DMs can only change the alternative scores, while the PW does not affect because the weights of set of metrics are similar for considered alternatives.

The research documents [45, 108] are used to build equations (6) and (7), which are used to aggregate the appropriateness ratings and priority importance weights against metrics. Appropriateness ratings against (1st level) measures can be computed by the following equation:

$$R_i = \frac{\sum R_{ij}}{C_{ijn}} = \frac{R_{ij1} + R_{ij2} + R_{ij3} + R_{ij4} + R_{ij5} \ldots\ldots\ldots\ldots R_{ijn}}{C_{ijn}}. \tag{6}$$

The appropriateness rating R_i of 1st level measures is computed from 2nd level metrics by using equation (6). In the above expression, $\sum R_{ij}$ is denoted as submission of appropriateness ratings R_{ij} of j_{th} 2nd level metrics, which are under i_{th} R_i (1st level measures).

Similarly, the priority importance weight of 1st level measures is computed from 2nd level metrics by using the following equation:

$$w_i = \frac{\sum w_{ij}}{C_{ijn}} = \frac{w_{ij1} + w_{ij2} + w_{ij3} + w_{ij4} + w_{ij5} \ldots\ldots\ldots\ldots w_{ijn}}{C_{ijn}}. \tag{7}$$

In this expression, $\sum w_{ij}$ is denoted as submission of priority importance weights of $w_{ij} j_{th}$ 2nd level metrics, which is under $i_{th} w_i$ (1st level measures).

4.2. Novel Fuzzy Performance Index (NFPI) towards calculating the results in %

$$\text{FPI} = \frac{\sum U_i \otimes w_i}{\sum w_i}. \tag{8}$$

In this expression, U_i and w_i are denoted as computed aggregated appropriateness rating and aggregated fuzzy priority weight as GTFN set of 1st level measures.

The centroid formula for defuzzification of the GTFN set $[A_i]$ is proposed [109]:

$$A_i = [a.b, c, d, \omega] \text{ Here, } [\omega_i = 1],$$

$$\overline{x}_0(A) = \frac{1}{3}\left[a + b + c + d - \frac{dc - ab}{(d + c) - (a + b)}\right], \tag{9}$$

$$\overline{y}_0(A) = \omega\frac{1}{3}\left[1 + \frac{c - b}{(d + c) - (a + b)}\right].$$

The crisp value $R(A)$ is as follows:

$$R(A) = \sqrt{\overline{x}_0 2(A) + \overline{y}_0^2(A)}. \tag{10}$$

In addition, the current performance and performance loss can be determined by the following [110]:

$$\text{NFPI} = \frac{R(A)_{\text{FPI}}}{R(A)_{\text{SFPI}}} \times 100\%, \tag{11}$$

$$\text{performance loss} = 100\% - \text{current performance}\ (\%). \tag{12}$$

Here, $R(A)_{\text{FPI}}$ is the defuzzification of the fuzzy performance index and $R(A)_{\text{SFPI}}$ is the defuzzification of the set/standard fuzzy performance index.

4.3. Computation of Fuzzy Performance Importance Index (FPII). After evaluating NFPI, the purpose of research work is to identify the weak and strong performing GSC metrics and measures and quantify their performances. The concept of computing FPII is over evaluated PWsaRs. It is found that the higher FPII of any metrics reflects the greater contribution towards GSC [96].

$$FPII_{ij} = w'_{ij} \times U_{ij},\quad w'_{ij} = \left[[(1,1,1,1;1)] - w_{ij} \right], \tag{13}$$

where U_{ij} is the aggregated fuzzy appropriateness ratings and w_{ij} is the aggregated fuzzy priority weights of k_{th} 2nd level metrics under i_{th} 1st level evaluation measures [96]. Since, if we directly calculate FPII, the important weights w_{ij} will neutralize the performance ratings in computing FPII; in this case, it will become impossible to identify the actual weak performing areas (low performance rating and high importance). If w_{ij} is high, then the transformation $[(1,1,1,1,w_{ij}) - w_{ij}]$ is low. Consequently, to elicit the metrics with low performance rating under high importance weights, the formula is used. $\text{FPII}_{ij} = [(1,1,1,1,w_{ij}) - w_{ij}] \otimes U_{ij}$.

4.4. Modified Degree of Similarity (DoS) Mathematical Model: Identification of Weak and Strong Performing GSC Metrics. The DoS approach enables the manager to measure the DoS between the two GTFN sets. The approach was only applicable to shortlist the strong and weak GSC metrics under the assessment of two GTFN sets by experts earlier. The existed DoS approach is modified by incorporating the scheme of negative and positive ideal solution. The modified DoS approach addressed the two drawbacks such as eliminate the requirement of two GTFN sets from experts and able to map the performance gap of metrics from its ideal value.

Let us suppose that, a degree of similarity between two fuzzy sets A and B is defined as follows:

$$S\,(A,B) = se \times sp, \tag{14}$$

where

$$se = \begin{cases} e^{-|a_1 - b_1|}, & a_1 = a_4 \text{ and } b_1 = b_4, \\ e^{-(k+z+h)}, & \text{otherwise}, \end{cases} \tag{15}$$

where k is the span deference, z is the center deference, and h is the center width deference between A and B, respectively.

$$k = \left| (a_4 - a_1) - (b_4 - b_1) \right|,$$
$$z = \left| \frac{(a_4 + a_1)}{2} - \frac{(b_4 + b_1)}{2} \right|, \tag{16}$$
$$h = \left| (a_3 - a_2) - (b_3 - b_2) \right|,$$

and

$$sp = \frac{DP + \min\ (P(A), P(B))}{DP + \max\ (P(A), P(B))},$$

$$P(A) = \sqrt{(a_1 - a_2)^2 + w_a^2} + \sqrt{(a_3 - a_4) + w_a^2} + (a_3 - a_2) - (a_4 - a_1),$$
$$P(B) = \sqrt{(b_1 - b_2)^2 + w_b^2} + \sqrt{(b_3 - b_4) + w_b^2} + (b_3 - b_2) - (b_4 - b_1), \tag{17}$$

where $P(A)$ and $P(B)$ are the perimeters of A and B. DP is an amending zero in the numerator and denominator $DP \in (0, 0.1)$:

$$\text{Preference orders of metrics in\%} = \frac{\{S\ (A,B)\}}{\text{Max}\{S\ (A,B)\}} * 100. \tag{18}$$

The computation of positive and negative ideal solution from defined FPII sets is as follows:

$$\text{IFPII}_{ij} = \max \left[\text{FPII}_{ij} \left[a_{ij}, b_{ij}, c_{ij}, d_{ij} \right] \right] B \in, \tag{19}$$

$$\text{IFPII}_{ij} = \min \left[\text{FPII}_{ij} \left[a_{ij}, b_{ij}, c_{ij}, d_{ij} \right] \right] C \in. \tag{20}$$

maxFPII_{ij} is the defined maximum value evaluated from defined FPII sets of each metrics, $B \in$ is the beneficial metrics, and $C \in$ is the cost/nonbeneficial metrics.

5. Empirical Case Research (Data Analyses)

This is an assumed empirical case study of automobile parts (gears and pistons) manufacturing industry, which is located at south part of Zambia. This company supplies the said attribute of parts to its partner's companies. The case study company realized the necessity to evaluate as well as measure own GSCM performance in the terms of GTFN set/scale, crisp value, and % and also identify the weak and strong performing metrics with quantifying their performance gap from ideal value under expert's opinion. From this contemplation, the authors conducted the literature review and audited the GSCM of case study industry and proposed a GTFN set-based theoretical GSCPM multi-level hierarchical index. The index consisted of measures and their interrelated metrics, in which green purchasing (C_1), green marketing (C_2), green production (C_3), green design (C_4), green packaging (C_5), and green recycling (C_6) are considered as measures at 1st level and disseminated into 2nd level metrics. The proposed index is displayed in Table 2, and definitions are shown in Table 3.

Later, equations (14), (18), and (19) are utilized to compute the weak and strong performing measures and metrics (by using backward rule [96]), depicted in Table 10, which assisted the managers to augment the GSC performances up to 100% by hunting the weak defined metrics.

The procedural steps for measuring the GSC performance are summarized as follows:

Table 2: A GTFN set-based GSCPM multilevel hierarchical index.

Measures (C_i)	Metrics (C_{ij})	References
Green procuring (GP), C_1	Fulfillment of state environmental regulations, $C_{1,1}$	[41, 111]
	Fulfillment of federal environmental regulations, $C_{1,2}$	[41, 112]
	Buying firm's environmental mission, $C_{1,3}$	[14, 113]
	Supplier's commitment in providing environmentally friendly packages, $C_{1,4}$	[55]
	Environmental audit for suppliers' internal management, $C_{1,5}$	[21, 114]
Green advertisement (GA), C_2	Green announcement, $C_{2,1}$	[115]
	Green delivery, $C_{2,2}$	[96, 115, 116]
	Collaboration with customers, $C_{2,3}$	[117]
	Green strategy of substitute product producers, $C_{2,4}$	[115]
	Anticipating improvement in product functional quality, $C_{2,5}$	[44, 115]
Green production (GPr), C_3	Internal multinational policies leading to advantage over competitors, $C_{3,1}$	[48, 101, 118]
	E-logistics and environment, $C_{3,2}$	[115]
	Skill policy entrepreneurs, $C_{3,3}$	[51, 119]
	Integration with green product suppliers, $C_{3,4}$	[120, 121]
Green design (GD), C_4	Design of products for reuse, recycle, recovery of material, and component parts, $C_{4,1}$	[59, 122]
	Public disclosure of environmental record, $C_{4,2}$	[11, 123–125]
	Reduction in environmental emissions, $C_{4,3}$	[123, 126]
Green packaging (GP), C_5	Integrating environmental thinking and innovation in packaging, $C_{5,1}$	[14, 120, 127]
	Eco-labeling of products or packaging, $C_{5,2}$	[52, 128, 129]
	Reduction in packaging weight, $C_{5,3}$	[57, 58, 123]
Green recovery (GR), C_6	Recycling degree to ensure full usage of resources, $C_{6,1}$	[117, 130]
	Recycling revenues, $C_{6,2}$	[49, 50, 131, 132]
	Returning product ratio, $C_{6,3}$	[8, 56, 133]

Table 3: Definitions of green supply chain performance metrics.

Notations	Descriptions	Notations	Descriptions	References
C_1	GP reflects the receiving of the eco-friendly materials/stuffs from vendors or purchase the materials from vendors under environmental practices.	$C_{1,1}$	It measures that the firm is able to maintain the level of pollution as per state environmental regulations. Its main objective is to protect human social life.	[41, 111]
		$C_{1,2}$	It measures that the firm is following the national environmental regulations. In order that, the firm can control the air, water, and on land pollution.	[41, 112]
		$C_{1,3}$	It measures that the firm able to take action for purchasing the products/services under green concerns. The environmental mission ensures the firm for a healthy environment for current and future generation.	[14, 113]
		$C_{1,4}$	It measures that the commitment of supplier must be ethical towards its partners regarding supplying of the raw/finished goods with eco-friendly packing.	[55]
		$C_{1,5}$	It measures the periodic performance evaluation scheme of the firm's partners/suppliers. It ensures the firm about its efficient internal management system towards purchasing the eco-friendly materials.	[21, 114]
C_2	GA directs the organization to execute the eco-friendly practices during the promotion of the goods/services towards public via media.	$C_{2,1}$	It measures the ability of firm to periodically declare the green policy across firm' employees as well as customers.	[115]
		$C_{2,2}$	It measures the ability of firm to provide the delivery of products to its partners/customers under environmental practices.	[96, 115, 116]
		$C_{2,3}$	It measures the customer's feedback system of firms' about firm's business, products, and different services.	[117]
		$C_{2,4}$	It measures the firm' efforts towards adopting the green practices to sale its substitute of identical product.	[115]
		$C_{2,5}$	It measures the planning of the firm towards improving the functionality of products/services.	[44, 115]
C_3	GPr states that manufacturing process should be designed to reduce the waste and high energy emission, resource's consumption, and so on.	$C_{3,1}$	It deals with the preplanned internal multinational policy of the firm to address the dynamic competitive global business environment.	[48, 101, 118]
		$C_{3,2}$	It measures the adaption of E-logistic software and technique for carting the data (documents) from firm to its trading partners without couriers.	[115]
		$C_{3,3}$	It measures that level of firm's recruitment policy to recruit only skill entrepreneurs, which help firm to survive at competitive market.	[51, 119]
		$C_{3,4}$	It measures that does the firm has interaction with other GSC suppliers.	[120, 121]
C_4	GD is concerned with the eco-design of entire production process.	$C_{4,1}$	It measures the ability of firm to recycle the recovered products after its useful life or can be refined on recovery.	[59, 122]
		$C_{4,2}$	It mapped that does the firm used to share the environmental policy and records with its suppliers or customers.	[11, 123–125]
		$C_{4,3}$	It mapped that does the firm able to reduce the substances, which leak and mix with environmental air.	[123, 126]

Table 3: Continued.

Notations	Descriptions	Notations	Descriptions	References
C_5	GP states that wrapping of manufactured products must be eco-friendly.	$C_{5,1}$	It measures that does the firm has green innovative idea and thinking and idea for acting on green packaging practice.	[14, 120, 127]
		$C_{5,2}$	It measures the degree of quality of eco-labeling/packing of products.	[52, 128, 129]
		$C_{5,3}$	It measures the ability of firm towards adapting the practice regarding reducing the weight of packing's material.	[57, 58, 123]
C_6	GR states that industries must compile the environmental protection policies and solutions in order to maintain the level of pollution as per the legal norms.	$C_{6,1}$	It measures the ability of firm for effective utilization of green recycling practices.	[117, 130]
		$C_{6,2}$	It measures the ability of firm to obtain the high revenue by green recycling products.	[49, 50, 131, 132]
		$C_{6,3}$	It measures the ability of firm to act swiftly to repair the returned products under the green practices.	[8, 56, 133]

Table 4: The scale for assigning ratings and weights against metrics.

Linguistic terms (Metrics ratings)	Linguistic terms (Priority weights)	GTFN sets
Absolutely poor (AP)	Absolutely low (AL)	(0, 0, 0, 0; 1.00)
Very poor (VP)	Very low (VL)	(0, 0, 0.02, 0.07; 1.00)
Poor (P)	Low (L)	(0.04, 0.1, 0.18, 0.23; 1.00)
Medium poor (MP)	Medium low (ML)	(0.17, 0.22, 0.36, 0.42; 1.00)
Fair (F)	Medium (M)	(0.32, 0.41, 0.58, 0.65; 1.00)
Medium good (MG)	Medium high (MH)	(0.58, 0.63, 0.80, 0.86; 1.00)
Good (G)	High (H)	(0.72, 0.78, 0.92, 0.97; 1.00)
Very good (VG)	Very high (VH)	(0.93, 0.98, 1.00, 1.00; 1.00)
Absolutely good (AG)	Absolutely high (AH)	(1.00, 1.00, 1.00, 1.00; 1.00)

Table 5: Appropriateness ratings (ARs) assessed by decision-makers against 2nd level metrics.

Measures (C_i)	Metrics (C_{ij})	ARs						
		DM_1	DM_2	DM_3	DM_4	DM_5	DM_6	DM_7
C_1	$C_{1,1}$	VG	AG	F	AG	MG	VG	AG
	$C_{1,2}$	VG	MG	AG	AG	AG	F	AG
	$C_{1,3}$	VG	AG	MG	MG	MG	AG	AG
	$C_{1,4}$	AG	MG	G	G	AG	MG	MG
	$C_{1,5}$	VG	MG	G	G	MG	G	G
C_2	$C_{2,1}$	F	MG	G	G	MG	G	G
	$C_{2,2}$	G	MG	G	G	MG	G	G
	$C_{2,3}$	F	G	MG	G	MG	G	G
	$C_{2,4}$	G	MG	G	G	G	MG	G
	$C_{2,5}$	VG	MG	G	G	MG	G	G
C_3	$C_{3,1}$	MP	MG	MG	VG	MG	G	G
	$C_{3,2}$	F	MG	VG	G	MG	MG	VG
	$C_{3,3}$	F	G	G	VG	MG	VG	G
	$C_{3,4}$	F	MG	VG	F	G	G	VG
C_4	$C_{4,1}$	F	MG	G	G	MG	VG	F
	$C_{4,2}$	F	MG	G	MG	MG	G	G
	$C_{4,3}$	MP	MG	G	G	MG	G	MG
C_5	$C_{5,1}$	F	G	MG	G	MG	G	G
	$C_{5,2}$	MP	MG	G	MG	G	MG	G
	$C_{5,3}$	MP	G	G	MG	MG	G	MG
C_6	$C_{6,1}$	MG	G	AG	AG	G	G	MG
	$C_{6,2}$	AG	VG	G	G	G	AG	AG
	$C_{6,3}$	VG	VG	VG	VG	VG	G	G

Table 6: Priority weights (PWs) assessed by decision-makers against 2nd level metrics.

Measures (C_i)	Metrics (C_{ij})	PWs						
		DM_1	DM_2	DM_3	DM_4	DM_5	DM_6	DM_7
C_1	$C_{1,1}$	AH	MH	VH	VH	AH	AH	H
	$C_{1,2}$	AH	MH	VH	VH	AH	AH	H
	$C_{1,3}$	MH	AH	VH	VH	AH	AH	H
	$C_{1,4}$	AH	MH	VH	VH	AH	AH	H
	$C_{1,5}$	AH	MH	VH	VH	AH	AH	H
C_2	$C_{2,1}$	VH	VH	MH	VH	MH	VH	ML
	$C_{2,2}$	MH	VH	VH	VH	MH	VH	ML
	$C_{2,3}$	MH	VH	VH	VH	MH	VH	ML
	$C_{2,4}$	VH	VH	MH	VH	MH	VH	ML
	$C_{2,5}$	VH	VH	MH	VH	MH	VH	ML
C_3	$C_{3,1}$	M	MH	M	MH	VH	VH	ML
	$C_{3,2}$	M	MH	M	MH	VH	VH	ML
	$C_{3,3}$	MH	M	M	MH	VH	VH	ML
	$C_{3,4}$	M	MH	M	MH	VH	VH	ML

Table 6: Continued.

Measures (C_i)	Metrics (C_{ij})	PWs						
		DM_1	DM_2	DM_3	DM_4	DM_5	DM_6	DM_7
C_4	$C_{4,1}$	M	MH	M	M	MH	ML	VH
	$C_{4,2}$	M	MH	M	M	MH	ML	VH
	$C_{4,3}$	M	MH	M	M	MH	ML	VH
C_5	$C_{5,1}$	VH	VH	AH	M	MH	ML	VH
	$C_{5,2}$	AH	VH	VH	M	MH	ML	VH
	$C_{5,3}$	VH	VH	AH	M	MH	ML	VH
C_6	$C_{6,1}$	MH	H	VH	AH	VH	VH	H
	$C_{6,2}$	H	MH	VH	AH	VH	VH	H
	$C_{6,3}$	MH	H	VH	AH	VH	VH	H

Table 7: Computed aggregated PWsaARs against evaluation 2nd level metrics.

Measures, (C_i)	ARs	PWs
C_1	(0.823, 0.857, 0.911, 0.930, 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
	(0.833, 0.860, 0.911, 0.930, 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
	(0.810, 0.839, 0.914, 0.940, 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
	(0.740, 0.779, 0.891, 0.931, 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
	(0.710, 0.766, 0.897, 0.930, 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
C_2	(0.623, 0.684, 0.837, 0.893, 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
	(0.680, 0.737, 0.886, 0.939, 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
	(0.623, 0.684, 0.837, 0.893, 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
	(0.680, 0.737, 0.886, 0.939, 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
	(0.710, 0.766, 0.897, 0.943, 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
C_3	(0.611, 0.664, 0.800, 0.886, 1.000)	(0.796, 0.851, 0.930, 0.955, 1.000)
	(0.663, 0.720, 0.843, 0.917, 1.000)	(0.796, 0.851, 0.930, 0.955, 1.000)
	(0.703, 0.763, 0.877, 0.871, 1.000)	(0.796, 0.851, 0.930, 0.955, 1.000)
	(0.646, 0.710, 0.829, 0.851, 1.000)	(0.796, 0.851, 0.930, 0.955, 1.000)
C_4	(0.596, 0.660, 0.800, 0.877, 1.000)	(0.767, 0.805, 0.905, 0.940, 1.000)
	(0.603, 0.636, 0.820, 0.844, 1.000)	(0.767, 0.805, 0.905, 0.940, 1.000)
	(0.581, 0.684, 0.900, 0.893, 1.000)	(0.767, 0.805, 0.905, 0.940, 1.000)
C_5	(0.623, 0.636, 0.837, 0.844, 1.000)	(0.857, 0.890, 0.952, 0.973, 1.000)
	(0.581, 0.636, 0.789, 0.844, 1.000)	(0.857, 0.890, 0.952, 0.973, 1.000)
	(0.760, 0.800, 0.789, 0.947, 1.000)	(0.857, 0.890, 0.952, 0.973, 1.000)
C_6	(0.870, 0.903, 0.900, 0.987, 1.000)	(0.777, 0.818, 0.916, 0.950, 1.000)
	(0.870, 0.923, 0.966, 0.991, 1.000)	(0.777, 0.818, 0.916, 0.950, 1.000)
	(0.760, 0.800, 0.789, 0.947, 1.000)	(0.777, 0.818, 0.916, 0.950, 1.000)

Table 8: Computed aggregated PWsaARs for 1st level measures.

Measures (Ci)	ARs	PWs
C_1	(0.617, 0.648, 0.723, 0.746; 1.000)	(0.661, 0.712, 0.807, 0.841, 1.000)
C_2	(0.663, 0.722, 0.869, 0.921; 1.000)	(0.822, 0.869, 0.946, 0.971, 1.000)
C_3	(0.656, 0.714, 0.837, 0.881; 1.000)	(0.796, 0.851, 0.930, 0.955, 1.000)
C_4	(0.593, 0.660, 0.900, 0.871; 1.000)	(0.767, 0.805, 0.905, 0.940, 1.000)
C_5	(0.655, 0.691, 0.805, 0.878; 1.000)	(0.857, 0.890, 0.952, 0.973, 1.000)
C_6	(0.833, 0.875, 0.855, 0.975; 1.000)	(0.777, 0.818, 0.916, 0.950, 1.000)

Step 1. Collection of experts' opinion (in linguistic terms) based on the priority importance weight and appropriateness ratings scale for individual evaluation metrics: The proposed index is simulated by the subjective assessment of a committee of seven experts. The experts such as DM_1, DM_2, DM_3, DM_4, DM_5, DM_6, and DM_7 were evaluated and selected from the case study industry. One executive was selected from each department such as purchasing-1, marketing-2, production-3, design-4, packaging-5, material recycling-6, and environmental protection-7 on the basis of their experience, interaction with the manufacturing activities, and strong qualification cum decision making capabilities. Entire DMs were at the top management hierarchy, which daily contributed their efficiency to supervise, oversight,

Table 9: Computed fuzzy performance importance index (FPII).

Measures (C_i)	FPII (fuzzy performance importance index)	Positive ideal solution (PIS)
C_1	(0.279, 0.247, 0.176, 0.148; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.282, 0.248, 0.176, 0.148; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.275, 0.242, 0.176, 0.149; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.251, 0.224, 0.172, 0.148; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.241, 0.221, 0.173, 0.148; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
C_2	(0.111, 0.090, 0.050, 0.026; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.121, 0.097, 0.053, 0.027; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.111, 0.090, 0.050, 0.026; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.121, 0.097, 0.053, 0.027; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.126, 0.100, 0.054, 0.027; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
C_3	(0.125, 0.099, 0.056, 0.040; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.135, 0.107, 0.059, 0.041; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.143, 0.114, 0.061, 0.039; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.132, 0.106, 0.058, 0.038; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
C_4	(0.139, 0.129, 0.076, 0.053; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.140, 0.124, 0.078, 0.051; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.135, 0.133, 0.086, 0.054; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
C_5	(0.089, 0.070, 0.042, 0.023; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.083, 0.070, 0.039, 0.023; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.109, 0.088, 0.039, 0.026; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
C_6	(0.200, 0.164, 0.076, 0.049; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.200, 0.168, 0.081, 0.050; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)
	(0.175, 0.146, 0.066, 0.047; 1.000)	(0.282, 0.248, 0.176, 0.149; 1.000)

and manage the middle and bottom level management activities.

Step 2. Approximation of the linguistic evaluation information by using GTFN set: Then, the expert's panel was instructed to choose the linguistic variables corresponding to GTFN set. The expert's panel elected 1–9 point linguistic scale, which transformed into the GTFN set as pointed out in Table 4. Next, the committee was instructed to express their subjective preferences (valuation score) in linguistic terms against 2nd level GSC metrics for determining fuzzy PWsaARs, depicted in Tables 5 and 6.

Step 3. Performance measurement: loss and gain: Then, the fuzzy performance index (FPI) is computed by employing equation (8), which used the evaluated PWsaARs data of 1st level measures. Therefore, the evaluated fuzzy performance index (FPI) is computed as (0.556, 0.653, 0.918, 1.061, and 1.000), which is compared with FPI (0.640, 0.780, 0.980, 1.250, and 1.000) proposed/set by the top management (considered corresponding to ideal performance-100%). Then, equations (11) and (12) are utilized to compute an overall GSC performance of firm, which was found 87% out of 100% (ideal performance). Therefore, the firm was suggested to hike 13% GSC performance to gain ideal performance limit.

Step 4. Classification of weak and strong performing metrics and its performance gap: After computing the Novel fuzzy performance index of industry, it became really essential to quantify the performance of measure and metrics and from its ideal value (100%) and also identify the weak and strong performing 2nd level metrics. To evaluate results, the fuzzy performance important index (FPII) and positive ideal solution (as entire metrics are beneficial in nature) against 2nd level metrics are computed by usage of equations (13) and (19), respectively. The results are revealed in Table 9.

6. Managerial and Practical Implications

The proposed research work assisted the manager to manage as well as improve the GSCP of own industry (if it is found beneath the proposed or expected GTFN set scale). The two conduits are fruitfully presented here and assisted the manager to manage and control the GSCP.

(1) The *managerial implication* is that the developed two GTFN set-based mathematical models with NFPI approach are executed over the proposed index, which assisted the manager to measure the performance of own industry in three forms such as crisp value, GTFN set scale, and %. The specialty of the proposed models is that these two models make the DMs trouble-less in terms of sharing bulk GTFN set information against metrics. Models are able to estimate the PWsaARs of 1st level measures by availing the subjective information of their interrelated metrics. The *practical implication* is that the same models can also be executed in future to tackle the extended hierarchy of index, i.e., 3rd, 4th, 5th, and other levels of hierarchy in mapping the same GSC performance of the same or different industry. To understand more practically, in case of 4th level

Table 10: Computed ranking order against evaluation 2nd level metrics.

Metrics (metrics, C_{ij})	GSC performance of metrics (%)	Performance gap from ideal value of metrics (%)	Preference orders
$C_{1,1}$	99.50	0.50	2
$C_{1,2}$	100.00	0.00	1
$C_{1,3}$	98.20	1.80	3
$C_{1,4}$	93.19	6.8	4
$C_{1,5}$	91.09	8.9	5
$C_{2,1}$	79.08	20.9	11
$C_{2,2}$	80.78	19.2	9
$C_{2,3}$	79.08	20.9	11
$C_{2,4}$	80.78	19.2	9
$C_{2,5}$	81.68	18.3	8
$C_{3,1}$	80.28	19.7	10
$C_{3,2}$	82.08	17.9	8
$C_{3,3}$	83.785	16.2	7
$C_{3,4}$	81.78	18.2	8
$C_{4,1}$	81.98	18.0	8
$C_{4,2}$	82.08	17.9	8
$C_{4,3}$	81.08	18.9	9
$C_{5,1}$	75.48	24.5	12
$C_{5,2}$	74.67	25.3	12
$C_{5,3}$	79.08	20.9	11
$C_{6,1}$	91.39	8.6	5
$C_{6,2}$	92.89	7.1	4
$C_{6,3}$	88.69	11.3	6

GSCPM index, DMs have to assign PWsaARs against solely 4th level metrics, while the PWsaARs information of 3rd, 2nd, and 1st level can be computed under back-propagation.

(2) The *managerial implication* is that the proposed modified DoS accompanied with FPII is executed over the proposed index to assist the manager for both objectives such as to trace the weak and strong metrics and measure the performance gap and closeness to its ideal performance. The introduction of PIS and NIS idea on FPII data helped the DMs to assign only one linguistic variable against each metrics to attain said both objectives; therefore, DMs would not be requested to assign two linguistic variables. The *practical implication* is that the manager can explored the same modified DoS along with FPII on extended GSCP metrics or different GSCP indexes of different industries for addressing the said objectives.

7. Conclusions

The conclusion of the research work strikes over the attainment of IS by usage of the GSCM strategy or architecture. The conclusion section enrolled the results, future research directions, and limitation of the proposed research work.

7.1. Results. The results of the research work are split into two parts as discussed. The GSC performance of case study firm is found 87%, which need to be improved up to 13% to satisfy the ideal value (100%) or meet the expected performance. The performance gaps of metrics are presented in Table 10. The authors recommended that weak metric's GSCP should be brought up to $C_{1,2}$. The authors also advised the managers to fulfill performance gap of metrics to attain the ideal GSC performance.

7.2. Future Directions. From future directions perspective, the extensive multilevel hierarchical index (intended to 1st, 2nd, 3rd, and 4th level) can be constructed and utilized with the proposed approach to measure the performance in different quotations. The manager is facilitated to improve own firm's GSCP if the performance is ascertained below the ideal limit/expected level by ramping up metrics GSC performance's gap. The industries, who utilize the GSC metrics as a strategy to sustain at competitive market, would gain the maximum benefit from the proposed research work. The industries can explore the presented idea periodically for measuring the performance and can improve the same if performance is found weak. GSCM scholars can utilize presented research work to boot up their wisdom about green measures and their metrics contribution towards sustainability, metrics identification new approach, and idea to build the advance/extended index.

7.3. Limitation. The research work ensures the managers to solve the performance measurement problem of metrics such as the weak metrics evaluation and identification problem and overall performance mapping of individual industry under the GTFN set-based GSCM index. Therefore, the multiobjective optimization, linear regression, and data forecasting problems cannot be solved using proposed mathematical models, approach, and index. The managers can write the C and JAVA programming for measuring the performance of own firm in different terms and also identify metrics performance gaps and closeness to ideal value in short span of time.

Data Availability

The data used to support the findings of this study are available in Tables 1–10.

Disclosure

This article is the part of remote employment research.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Research Article

The Most Effective Functioning of Competitive Supply Chain Pricing Based on Social Responsibility Dimensions: A Case Study of Oil Products of Knowledge-Based Companies

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In today's competitive environment, taking the advantage of supply chain which is both effective and efficient is a competitive advantage. An adequate supply chain has a multifaceted structure that focuses on integrating all factors, including pricing. The final product is delivered to customers based on maintaining market values and increasing strategic interactions. Present study aims to present the most effective functioning of competitive supply chain pricing in accordance with aspects of social responsibility. In doing so, we conducted a case study on oil-related products of Iranian knowledge-based companies. A combined analysis with 15 university-level industrial management experts was employed in this study to establish the components (competitive supply chain pricing function) and research propositions (dimensions of social responsibility). Twenty managers of knowledge-based enterprises in the oil field evaluated the components and propositions identified in the form of matrix questions using interpretative rating (IRP). The results showed that the proposition of the ethical dimension is the most effective measure of the social responsibility of knowledge-based companies in the oil field, creating competitive supply chain pricing functions based on value. This result shows that, under the ethical dimension of social responsibility, processes of competitive supply chain pricing are formed in accordance with the customer values and, according to the strategic relationship between the company and the economy with regional and global partners, maintaining values are a critical factor in developing our interactions between pricing factors. Given the results, in the first step for success, knowledge-based companies are recommended to consider the priorities of professional ethics in addition to knowledge in order to be able to gain the trust of customers by understanding their functional nature in the country's developing economy. In this situation, the pricing process based on the creation of comprehensive values for customers can help to increase the company's competitive position and make these companies to be at the first level of strategic interactions with companies that use petroleum products.

1. Introduction

One of the biggest problems faced by organizations, especially knowledge-based businesses, is that as political, social, cultural, and economic change intensifies, competitive functions based on that change will become more complicated because the status of expectations and social approaches will change [1]. The significant point is that an institution or organization will be able to have the capacity to participate and support stakeholders if it implements competitive processes with social responsibility considerations in mind in order to sustain the majority of interests. On the other hand, in today's competitive world, other traditional methods of management in supply chain processes that sought less integration in their procedures do not have the required efficiency because this area has seen significant change as a result of environmental change, social development, technological progress, and growing cultural contradictions [2]. Making the right decision and selecting the appropriate option among many available ones in a variety of areas, such as choosing the best manufacturer, distributor, location to draw in customers, business partners for forming integrations, pricing strategy, and similar matters, is crucial for decision-making to produce integrated values in supply chain management. These choices range from trivial difficulties to serious and important topics.

In many cases, if the decision is incorrect, it would impose high costs on companies operating in a competitive environment [3]. Hence, organizations can no longer achieve a competitive advantage and increase their market share as a separate product or service unit. They require a well-planned and principled partnership with their suppliers and customers. As a result, organizations should partner with each other in integrated supply chains rather than isolated islands [4]. One of the dimensions of integration is value integrity in supply chain pricing functions, which is based on how well the manufacturer collaborates strategically with supply chain partners to provide high-quality products, set prices that are tailored to the needs of the market and its customers, and jointly manage internal and external organizational processes [5]. Since integration of supply chain value is a promising yet complicated tool that is still considered as a weapon to reach maturity in a competitive environment to enhance the development dimensions of businesses [6], the need to pay attention to it can help companies as a competitive advantage, even in proper pricing, to create a level of stability for flexibility in the face of an ever-changing environment. Therefore, during the past years, many researchers have tried to develop a level of value integration to achieve more competitive advantages based on the creation of various paradigms such as stability and agility based on the flexibility of the supply chain. The significant point is that the supply chain must be flexible in multiple dimensions such as pricing; its operation has always been a subject to various uncertainties, such as customer demand and supplier capacity under turbulent economic conditions [7]. In other words, with increasing structural complexity at the level of markets and production processes, meeting customer needs should be achieved in the shortest possible time by improving the degree of supply chain flexibility, since this indicates the system's capacities and ability to react rapidly and effectively to both internal and external changes. Considering the importance of this research, it is essential to note that competitive supply chain pricing generally reduces the process cycle time and reimplementation. At the same time, it can help increase competitive effectiveness and improve value chain integrity in the supply chain. To the best of our knowledge, no study has been so far conducted on the most effective functioning of competitive supply chain pricing based on social responsibility dimensions regarding oil products of knowledge-based companies. Therefore, this research aims to investigate the most effective functioning of competitive supply chain pricing in accordance with the dimensions of social responsibility regarding the oil-related products of Iranian knowledge-based companies.

2. Theoretical Foundations

2.1. Social Responsibility. Social responsibility as one of the organizational philosophies is one of the challenging functional issues in the social environment, which, despite its many complexities, has many hidden and overt dimensions. Numerous terms, such as strategic philanthropy, corporate citizenship, social responsibility, and others, are used to characterize corporate responsibility [8]. According to the words, it can be said that each of them has a specific view on the role of the organization in society. The dominant paradigm that underlies corporate social responsibility focuses on creating shared value [9]. In 1971, the Committee For Economic Development defined corporate social responsibility as the interaction between society, profession, philosophy of existence, and the social nature of an organization. The presence of responsibility and accountability for the interests of the majority of stakeholders expands the cornerstone of this concept in societies. These interests should add to the sum of social, human, cultural values, etc., and cause motivation in individuals [10].

On the other hand, Van De Velde et al. [11], in a precise definition, consider social responsibility to include all policies that combine functions and value business with the interests of all stakeholders, including customers, employees, and citizens that may contribute essentially in the sustainable development of societies. In another definition, corporate social responsibility means the organization's obligation to consider stakeholders' interests, which goes beyond the legal requirements. Its purpose is to minimize any harm caused by the organization's activities and maximize long-term beneficial effects on society. Social responsibility has many consequences for organizations. Recognizing these effects can motivate organizations to perform their social responsibilities. Increasing the organization's legitimacy, observing the interests of society, and promoting self-control are among these effects [12].

2.2. Sustainable Supply Chain Management. Over the past 20 years, a great deal of research has been conducted on the idea of sustainable supply chain management. The 1960s saw a lot of development work, mostly on the economic side of sustainable development [13]. In the years after the 1960s, the noneconomic factors of development activities were also considered, and in the 1980s, the concept of sustainable development was introduced. With the overall development of this concept, various dimensions of the supply chain sustainability literature, whether in social, economic, cultural, or environmental dimensions, were discussed, which often included common goals. In a classification, Elkington

[14] divided the sustainability literature into three basic aspects: social, economic, and environmental. The significant point is that before 2000, no coherent, integrated, and independent definition of sustainable supply chain management was provided explicitly. But from 2001 onwards, the descriptions included various dimensions of sustainability more purposefully and with wider dimensions. According to one definition, business sustainability can be included into supply chain management. The primary elements of supply chain management are connected to the corporate sustainability traits [15].

Besides, According to Srivastava [16], who defines sustainable supply chain management from an environmental point of view, it encompasses product design, material sourcing and selection, production procedures, delivery of the finished product to customers, as well as the management of products after their useful lives. On the other hand, Shen [17], given the significant effect that supply chain network design has on companies' flexibility, profitability, and competitive competencies, asserts that network design is one of the most important strategic choices in supply chain management and that network design can influence supply chain sustainability and long-term profitability. As mentioned today, the process of sustainable chain management definitions revolves around a three-dimensional cycle (3BL), including social, economic, and environmental. Other exciting aspects of the proposed reports include external stakeholder pressures and the idea that sustainable supply chain management goes beyond the traditional business concept but is also related to economic performance [18]. By focusing on collaboration between supply chain partners, sustainable supply chain management is viewed from an operational perspective as a subset of internal and external activities. The methodical coordination of crucial interorganizational processes is what defines strategic integrity, transparency, and the accomplishment of an organization's social, environmental, and economic goals while enhancing the long-term financial performance of businesses and their supply chains [19].

2.3. Supply Chain Flexibility. Today, flexibility has become a common term among managers, researchers, and supply chain consultants. But what are the meaning and concept of flexibility? Flexibility points to "the ability of a system to survive, adapt, and grow in the face of change and uncertainty" [20]. In another definition, flexibility is "the ability of the supply chain to return to the original state (before being disturbed) or move to a new state that is more desirable than before" [21]. Regarding supply chain flexibility, we can only refer to conceptual studies, including reviewing the literature and definitions or principled guidelines based only on compelling examples [22]. According to Lummus and Vokurka [23], the ability of the supply chain to quickly respond to consumer demand and the degree to which production capacity may be adjusted in reaction to shifting market conditions are both examples of supply chain flexibility. Supply chain flexibility is presented by Vickery et al. [24] in Figure 1.

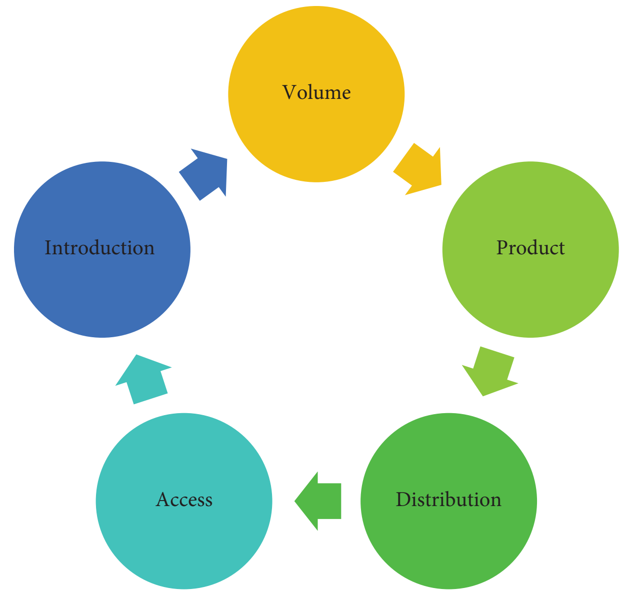

Figure 1: Five-dimensional model of supply chain flexibility (source: author).

Vickery et al. [24] believed that from the above five dimensions, there is an interrelationship between the first two components, namely, volume flexibility and product flexibility, leading to supply chain flexibility in manufacturing systems, access, and distribution flexibility follow market process approaches. New product flexibility is also related to R&D teams to develop supply chain flexibility functions [7]. Process flexibility and distribution flexibility were two of the most important components of supply chain flexibility according to Sawhney [25]. Three aspects of supply chain flexibility were also mentioned by Swafford et al. [26]: sourcing flexibility, production flexibility, and distribution flexibility.

2.4. Integrating Supply Chain Pricing Values. The degree to which the manufacturer collaborates with supply chain partners and as a group manages procedures inside and outside the firm to generate competitive advantages is known as supply chain pricing integration [27]. Stevens [28] first considered value integration to include the following three dimensions (Figure 2).

As it can be seen, according to Stevens [28], functional integration, internal integration, and external integration are known as the three levels of integration, which includes integration with suppliers and customers. Then, researchers identified and introduced other dimensions of integration. For example, Lee and Hang [29] also considered supply chain value integration to include as the following model (Figure 3).

The researchers described the three elements of supply chain value integration, information integration, coordination and resource sharing, and organizational connection linkage with partners, but placed particular emphasis on relationship integration in light of the dynamic environment. Consequently, three integrated supply chains

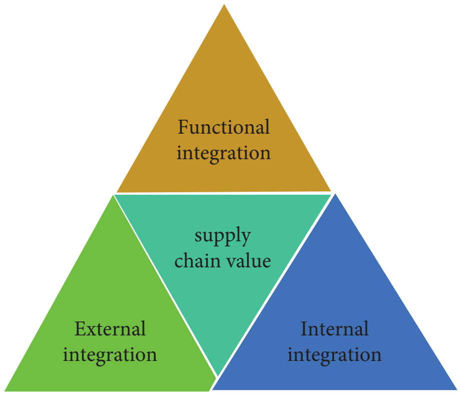

Figure 2: A 3D approach to supply chain value integration (source: author).

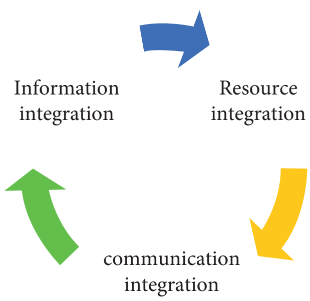

Figure 3: Supply chain value integration, according to Lee and Hang [29].

were introduced: one with internal integration, one with suppliers, and one with customers [30, 31]. According to various studies, in this study, internal and exterior integration are the two dimensions that make up integration [32], while customer integration and supplier integration are the two sizes that make up external integration. Internal integration is a process of cross-functional contact, collaboration, coordination, communication, and cooperation that combines functional domains into a unified organization, according to Wong et al. [30]. He thinks that internal integrity has a big effect on cost and quality. According to Baofeng [33], a company has high levels of internal integration when all departments have access to accurate and timely information from other departments, the information systems utilized by those departments are linked, and there are practical tools for connecting all the jobs. The process of interacting and working together with suppliers to ensure a sufficient flow of supplies is known as supplier integration. Supplier integration increases capacity and improves performance indicators such as delivery, quality, and cost. The cooperation and strategic coordination of a central organization with its clients is referred to as supplier integration. According to Ataseven and Nair [4], this aspect of integration contributes to a deeper comprehension of customer and market expectations and opportunities and facilitates a quicker and more precise supply-demand reaction to customer demands and objectives. The following research inquiries are based on the theoretical underpinnings provided:

(1) What are the functional elements of supply chain pricing competition that serve as the foundation for interpretive analysis?
(2) What are the social responsibility tenets that interpretive analysis refers to?
(3) In knowledge-based oil firms, what pricing method for the supply chain is the most competitive and effective in terms of social responsibility?

2.5. Literature Review. Here, we will review and evaluate some domestic and foreign studies conducted in the field of the subject raised in the current research.

Taghavifard et al. [34] in their study entitled "The role of corporate social responsibility in the adoption of green supply chain management with regard to the mediating role of big data analysis" stated that the findings of the joint analysis of social responsibility and green supply chain management can help businesses adopt and execute green supply chain management, and they can also help businesses enhance performance by adhering to green supply chain management. In order to attain effective performance, their study looked into how effective elements affected the moderating role of big data analysis in the relationship between social responsibility and green supply chain management. Their research has an applied goal and use correlational data collection techniques to gather descriptive information. 426 supply chain, green supply chain, social responsibility, and big data analysis managers from small and medium-sized businesses in the provinces of Golestan, Mazandaran, and Tehran make up the statistical population. The questionnaire was randomly distributed to 252 managers of these organizations, with the minimum necessary sample size calculated to be 201 individuals based on Morgan's table. 213 returned completed questionnaires were subjected to confirmatory factor analysis (CFA). To address the research hypotheses, structural equation modeling and partial least squares methods have been applied. Wang et al. questionnaires for social responsibility variables, Raut et al. questionnaires for big data analysis variables, and questionnaires for firm performance were used to electronically collect study data. According to the research, corporate social responsibility increases businesses' awareness of and willingness to engage in environmentally friendly practices. On the other hand, by enabling access to thorough information as well as integrating and deploying resources connected to data analysis, the ability to analyze big data can change the impact of a company's social responsibility in the direction of greenness. As a result, business performance will also increase. The findings also demonstrated that among the key elements of big data analysis, social practices, supply chain management, lean management, and comprehensive quality management, all have a favorable impact on it. By contrast, environmental, organizational, and financial practices had no impact on big data analysis.

Parsaeifar et al. [35] in their study entitled "pricing in a three-tier competitive supply chain using the game theory approach" looked at a three-tier supply chain with various retailers, a single manufacturer, and various suppliers, where there is rivalry at each level of the chain and the manufacturer provides the retailers with a variety of goods. There are two ways to display competition between chain members: horizontally and vertically. A nonlinear mathematical model including competition and cooperation modeling on pricing strategy is offered. The relationships between supply chain participants in the noncooperative game style are also taken into account in this model. Demand is a function of retail price and pricing of rival retailers, according to their article. In this model, the manufacturer is presumptively more powerful and imposes his judgments on suppliers and retailers; in other words, the manufacturer assumes the position of the leader, while the other members assume the role of the followers, creating a Stackelberg-type of rivalry. Finally, the model's most crucial parameter underwent sensitivity analysis.

Najafikhanshan and Omrani [36] in their study titled "presenting a model for competitive pricing in the supply chain network with traditional and online sales channels" stated that price competition is one of the major issues that companies face. However, many companies are faced with not having a suitable strategy in terms of price competition. Nowadays, game theory plays an essential role in finding equilibrium prices in traditional and Internet sales channels. Considering the increase of competition in the markets and the desire of companies to use Internet channels, it is necessary to design models for the pricing of goods in different channels. So far, there has been little research in Iran about pricing in online sales channels. In their article, a model is presented for finding prices in different sales channels based on game theory. For this purpose, competition in the market is modeled and pricing is performed based on Stackelberg's theory. Therefore, the price function for the orange juice product of Orom Narin Shadlee Company was designed in traditional and Internet sales channels, and then game theory was used to find the equilibrium price in the said channels.

Wang et al. [37] in their study entitled "corporate social responsibility of green supply chain management and company performance considering big data analysis" stated that both internal and external social responsibility have a positive impact on supply chain management. The findings also indicate that green supply chain management improves a company's performance and that big data analysis has a beneficial moderating influence on the relationship between green supply chain management and external social responsibility.

Raut et al. [38] in their study entitled "the role of big data analysis as a mediator between sustainable business performance of the supply chain and key factors (i.e., lean practices, social environmental, organizational measures, financial supply chain, and comprehensive quality management)" stated that total quality management has no effect on big data analysis. Also, the results show that big data analysis has a favorable impact on the supply chain's sustainable business success.

Dubey et al. [39] in their study titled "investigation of how and when to create the ability to analyze big data to improve supply chain agility and gain competitive advantage" stated that big data analysis has a positive and significant impact on agility of supply chain and organizations' competitive advantage. In addition, the results show that organizational flexibility adjustment has a positive and significant effect in adjusting the path of joining big data analysis and supply chain agility; however, contrary to the authors' opinion, no support was found for the effect of adjusting financial shows on the path of joining to the big data analysis and competitive advantage.

Younis et al. [40] in their qualitative study entitled "the relationship between garlic supply chain management practices and company performance" identified some of the primary causes for why approaches for managing the supply chain for garlic could not have an impact on many aspects of business performance. Most of the issues were related to implementation included environmental design, procurement of garlic, environmental cooperation, and reverse procurement.

3. Methodology

Diagonal matrix analysis based on the multicriteria decision-making (MCDM) method is one of the matrix analysis techniques [41]. However, straightforward MCDM techniques are divided into categories such as AHP or ANP, depending on where the analysis is placed [42]. The analytical hierarchy process (AHP), which is employed in multicriteria decision analysis, is more broadly categorized as the analytic network process (ANP). ANP constructs a decision problem as a network, whereas AHP builds it into a hierarchy with a goal, decision criteria, and alternatives. Depending on the design of the choice problem based on each of the criteria related to the kind of the analysis, each alternative is either examined separately or in pairs compared to the other possibilities. A process consisting of 7 phases is used to carry out AHP and establish the priorities of criteria and subcriteria; each stage is detailed below.

(i) Stage 1: Collection of experts' answers

In this stage, first, the main criteria based on the purpose and subcriteria compared to the primary standard were compared using Saaty's pairwise questionnaire with a nine-point scale in pairs.

(ii) Stage 2: Fuzzification of experts' viewpoint

In this stage, the viewpoint of experts was quantified through the Fuzzy scale. The Fuzzy scale used in the Fuzzy hierarchical analysis process method based on Chang's method [42] is presented in Table 1.

In this stage, the questionnaires were given to the experts, and they answered them using Saaty's nine-point scale. Therefore, the matrix of pairwise comparisons is now formed using the fuzzification of the experts' viewpoint. Now, the point is what to do when faced with multiple respondents? Based on Chang's Fuzzy hierarchical analysis method [42], the arithmetic means of the views need to be calculated. Therefore, after collecting the experts

Table 1: Crisp, Fuzzy, and Fuzzy inverse numbers of pairwise comparisons based on Chang method [42].

Comparison of i to j	Crisp number	Fuzzy numbers			The inverse of fuzzy numbers		
		Lower limit (L)	Middle limit (M)	Upper limit (U)	Lower limit (L)	Middle limit (M)	Upper limit (U)
Equally preferred	1	1	1	1	1.000	1.000	1.000
Intermediate	2	1	2	3	0.333	0.500	1.000
A little preferred	3	2	3	4	0.250	0.333	0.500
Intermediate	4	3	4	5	0.200	0.250	0.333
Strongly preferred	5	4	5	6	0.167	0.200	0.250
In between	6	5	6	7	0.143	0.167	0.200
Very strongly preferred	7	6	7	8	0.125	0.143	0.167
Intermediate	8	7	8	9	0.111	0.125	0.143
Completely preferred	9	8	9	10	0.100	0.111	0.125

"opinions with Saaty's nine-point scale and fuzzifying the experts" opinions, the experts' views were added using the Fuzzy average. To calculate the mean view of n respondents, the Fuzzy mean will be calculated as follows:

$$f_i = (l_i, m_i, u_i),$$

$$\text{Fuzzy Average} = \left[\frac{l_1 + l_2 + l_3 + \cdots l_n}{n}, \cdot \frac{m_1 + m_2 + m_3 + \cdots m_n}{n}, \cdot \frac{u_1 + u_2 + u_3 + \cdots u_n}{n}\right]. \tag{1}$$

(iii) Stage 3: Calculating the Fuzzy sum of each row

The eigenvector must be determined once the fuzzy average of the obtained pairwise comparison matrix has been determined. To begin, the following formula is used to determine the Fuzzy sum for each row:

$$\sum_{j=1}^{n} M_{g_1}^{j} = \left(\sum_{j=1}^{n} l_i^j, \sum_{j=1}^{n} m_i^j, \sum_{j=1}^{n} u_i^j\right). \tag{2}$$

(iv) Stage 4: Calculating the Fuzzy normalized weight (S_i)

After calculating the Fuzzy sum of each row using formula (3), the normalized Fuzzy weight (Fuzzy compound expansion) of each criterion is calculated.

$$S_i = \sum_{J=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{g_i}^{j}\right]^{-1}. \tag{3}$$

The Fuzzy compound expansion is determined by dividing the total of that criterion's values by the total of all preferences (column elements). The Fuzzy sum of each row is multiplied by the inverse of the aggregate because the values are fuzzy.

(v) Stage 5: Defuzzification and calculating the eigenvector

There are various methods for defuzzification of the obtained values. One method was used for defuzzification of the calculated values for calculating the possibility and the crisp number. In this study, possibility degrees are calculated, and the crisp number calculations are used. Due to the consistency of the results and the simplicity of understanding the crisp measures. Defuzzification to calculate the crisp number is as follows:

$$x_{\max}^{1} = \frac{l + m + u}{3}, \quad x_{\max}^{2} = \frac{l + 2m + u}{4}, \quad x_{\max}^{3} = \frac{l + 4m + u}{6}, \tag{4}$$

$$\text{Crisp Number} = Z^* = \max\left\{x_{\max}^1, x_{\max}^2, x_{\max}^3\right\}.$$

(vi) Stage 6: Evaluating the inconsistency rate

In this study, to calculate the consistency, Gogus and Butcher's method was used, the description is given below. Gogus and Boucher suggested that each Fuzzy matrix should yield two matrices: the middle number and the Fuzzy number limit. Then, using Saaty's method, the matrix's consistency rate (CR) may be determined. The following would be the formula for calculating the consistency rate for fuzzy pairwise comparison matrices.

Step 1: Two matrices make to the fuzzy triangular matrix. The second matrix is made up of the upper and lower geometrical limits of triangular numbers, whereas the first matrix is made up of the intermediate numbers of triangular judgments $A^g = \sqrt{a_{iju} \cdot a_{ijl}}$.

Step 2: Using Saaty's approach, the vector of weights for each matrix is calculated as follows:

$$w_i^m = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ijm}}{\sum_{i=1}^{n} a_{ijm}},$$

$$w^m = [w_i^m],$$

$$w_i^g = \frac{1}{n}\sum_{j=1}^{n} \frac{\sqrt{a_{iju} \cdot a_{ijl}}}{\sum_{i=1}^{n}\sqrt{a_{iju} \cdot a_{ijl}}}, \tag{5}$$

$$w^g = [w_i^g],$$

Step 3: For each matrix, the biggest eigenvalue is determined as follows:

$$\lambda_{\max}^{m} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ijm} \left(\frac{w_j^m}{w_i^m} \right),$$
$$\lambda_{\max}^{g} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} \sqrt{a_{iju}.a_{ijl}} \left(\frac{w_j^g}{w_i^g} \right). \quad (6)$$

Step 4: The following equation was used to determine the Consistency Index (CI):

$$CI^{m} = \frac{\left(\lambda_{\max}^{m} - n\right)}{(n-1)},$$
$$CI^{g} = \frac{\left(\lambda_{\max}^{g} - n\right)}{(n-1)}. \quad (7)$$

Step 5: We must divide the CI index by the random index (RI) value in order to determine the consistency rate (CR). If the outcome is less than 0.1, the matrix is regarded as valid and consistent. Saaty created 100 matrices using random numbers and the requirement that they be reciprocal in order to get the values of random indexes (RI). He then determined the values of inconsistencies and their mean. Saaty's random index (RI) table cannot be utilized, even if Saaty's (1–9) scale is employed, because the numerical values of fuzzy comparisons are not necessarily integers. As a result, the geometric mean typically changes fuzzy comparisons' numerical values into noninteger numbers. As a result, 400 random matrices were produced by Gogus and Boucher to construct the random indices (RI) table for fuzzy pairwise comparison matrices (Table 2).

The Fuzzy triangular number's middle number was initially randomly generated in the range [1/9, 9] and it was also generated reciprocally in order to create random matrices. The upper limit, lower limit, and middle values in the interval were then generated randomly for each triangular number. The value of their random index was then calculated by splitting the resulting random matrix into two matrices of the central limit and the geometric mean of upper and lower limits. It should be noted that it is more significant than the inconsistent value in the column. The reason for this discrepancy is that while the range of random numbers generated for the middle limit is [1/9, 9], the range of random numbers generated for the lower and upper limits based on the middle number generated is more constrained and hence less likely to be inconsistent.

We compared the two matrices' inconsistency rates with the 0.1 thresholds by computing the inconsistency rates using the following equation:

Table 2: Random indices (RI), (source: author).

Matrix size	RI^m	0
1	0	0
2	0	0
3	0.4890	0.1796
4	0.7937	0.2627
5	1.0720	0.3597
6	1.1996	0.3818
7	1.2874	0.4090
8	1.3410	0.4164
9	1.3793	0.4348
10	1.4095	0.4455
11	1.4181	0.4536
12	1.4462	0.4776
13	1.4555	0.4691
14	1.4913	0.4804
15	1.4986	0.4880

$$CR^{g} = \frac{CI^{g}}{RI^{g}},$$
$$CR^{m} = \frac{CI^{m}}{RI^{m}}. \quad (8)$$

If both indices are less than 0.1, the fuzzy matrix will be consistent. The decision-maker would be prompted to reassess the priorities if both numbers were higher than 0.1. Additionally, the decision-maker must consider the values of the middle numbers (limits) of fuzzy judgments if only one of the two values is larger than 0.1.

(vii) Stage 7: Total weight of the subcriteria

The relative importance of each subcriteria is multiplied by the weight of that criterion to determine its relative weight.

Similar to the analysis process in multicriteria decision-making methods, the related elements and propositions to improve the choice of the most effective functioning of competitive supply chain pricing based on social responsibility are identified through a meta-synthesis process in this study. The problem structure is explored through a pairwise comparison between the research components used as a basis (competitive supply chain pricing functions) and the research propositions (dimensions of social responsibility). The lack of theoretical coherence in terms of concepts and theories related to this field has thus led this research to seek to develop an integrated approach to competitive supply chain pricing functions, and as a result, it can be said that this research falls under the category of developmental research in terms of the nature of the result. However, based on the data type, this research is hybrid because, in the qualitative section, it seeks to identify the elements and hypotheses of the functioning of competitive supply chain pricing and social responsibility through theoretical screening based on the systematic meta-synthesis method. Then, it investigates a model of the effectiveness of social responsibility on the functioning of competitive supply chain pricing through the diagonal method. One of the most effective interpretative ranking processes (IRPs) is often one that bases decisions on the elements and hypotheses that are examined in pairwise comparison and matrix analysis [43]. According to the above justifications, the interpretative rating process (IRP) might be expressed in the following ways:

The various steps of interpretive ranking are shown in Figure 4, respectively.

Step 1: A list of the standards and factors were taken into account in this study.

Step 2: A substantial relationship between the criteria and the variables found in Step 1 is defined with regard to each pair of standards. A conceptual connection between the system's parts that is appropriate to the purposes of the system in terms of meaning and substance is referred to as a substantive relationship. Assume, for instance, that a cloud drives rain; in this case, "cloud" and "rain" are system components, and their substantive relationship is what generates the rain. Other phrases such as "takes priority over," "supports," "prevents from," "reports to," and "affects" can also demonstrate these interactions. Definitional relationships, close relationships, effect relationships, temporal links, judicial relationships, and mathematical relationships are only a few of the several types of substantive interactions that can exist between two components. We exploited the cause-and-effect relationship in this study.

Step 3: To highlight the pairwise interactions between competitive supply chain price functions based on social responsibility dimensions, a structural self-interaction matrix (SSIM) is created for barriers.

Step 4: A structural self-interactive matrix is used to create a reachability matrix, which is then tested for transitivity. The content connection of a core premise in interpretive structural modeling is transitivity. Transitivity describes the relationship between variables A and B as well as the relationship between variable B and the unstable variable C. As a result, variable A is also related to variable C (Figure 5).

Step 5: The fourth step's reachability matrix is broken down into tiers.

Step 6: A directional graph is created based on the relationships specified in the reachability matrix, and the transitivity relationships are removed.

Step 7: By replacing the names of the variables with criteria instead of nodes, the completed diagram is converted into interpretive structural modeling.

Step 8: Interpretive structural modeling, created in step 7, is examined to ensure that its content is consistent. If there is a discrepancy, the necessary adjustments will be made.

3.1. Structural Self-Interactive Matrix (SSIM). To establish meaningful linkages between the variables, the interpretive structural modeling advises employing expert judgment based on various management techniques, such as brainstorming and nominal groups. Regarding any criteria pair, the experts were consulted for their opinion on how the two criteria relate to one another. To emphasize the relationship's simplicity, English letters were not utilized in the source; instead, the integers −1, 1, 2, and 0 were used.

1: If only criterion j is impacted by criterion i.

2: If both criterion I and j have an impact on each other.

−1: If only criterion I is impacted by criterion j

0: If the two criteria, I and j, do not effectively relate to one another.

Garfield's instructions [44] state that the relationship between competitive supply chain pricing functions based on social responsibility dimensions has been established using expert judgments.

3.2. Initial Reachability Matrix. The reachability matrix's (i, j) cell becomes one and the (j, i) cell becomes zero if the intersection of the criteria (i, j) in SSIM is 1.

The (i, j) cell and the (j, i) cell in the reachability matrix both become 1 if the intersection of the criteria (i, j) in SSIM equals 2.

Both the (i, j) cell and the (j, i) cell in the reachability matrix become zero if the intersection of the criteria (i, j) in SSIM is 0.

The (i, j) cell in the reachability matrix becomes 0 and the (j, i) cell becomes 1 if the intersection of (i, j) in SSIM is −1.

$$D = \begin{bmatrix} & C_1 & C_2 & \cdots & \cdots & C_n \\ C_1 & 0 & d_{12} & \cdots & \cdots & d_{1n} \\ C_2 & d_{21} & 0 & \cdots & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & 0 & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & 0 & \vdots \\ C_m & d_{m1} & d_{m2} & \cdots & \cdots & 0 \end{bmatrix}. \tag{9}$$

The initial reachability matrix, matrix D, also displays competitive supply chain price functions based on social responsibility dimensions by substituting the digits zero and one for the signs.

3.3. Final Reachability Matrix. In order to make the final reachability matrix for criteria compatible with the initial reachability matrix, the extended relationship is taken into consideration. In order to achieve this, the starting matrix needs to be in $k + 1$ exponentiation in order to maintain a stable status $M^k = M^{k+1}$. By doing this, some zero components will be converted to 1 and displayed as (1^*).

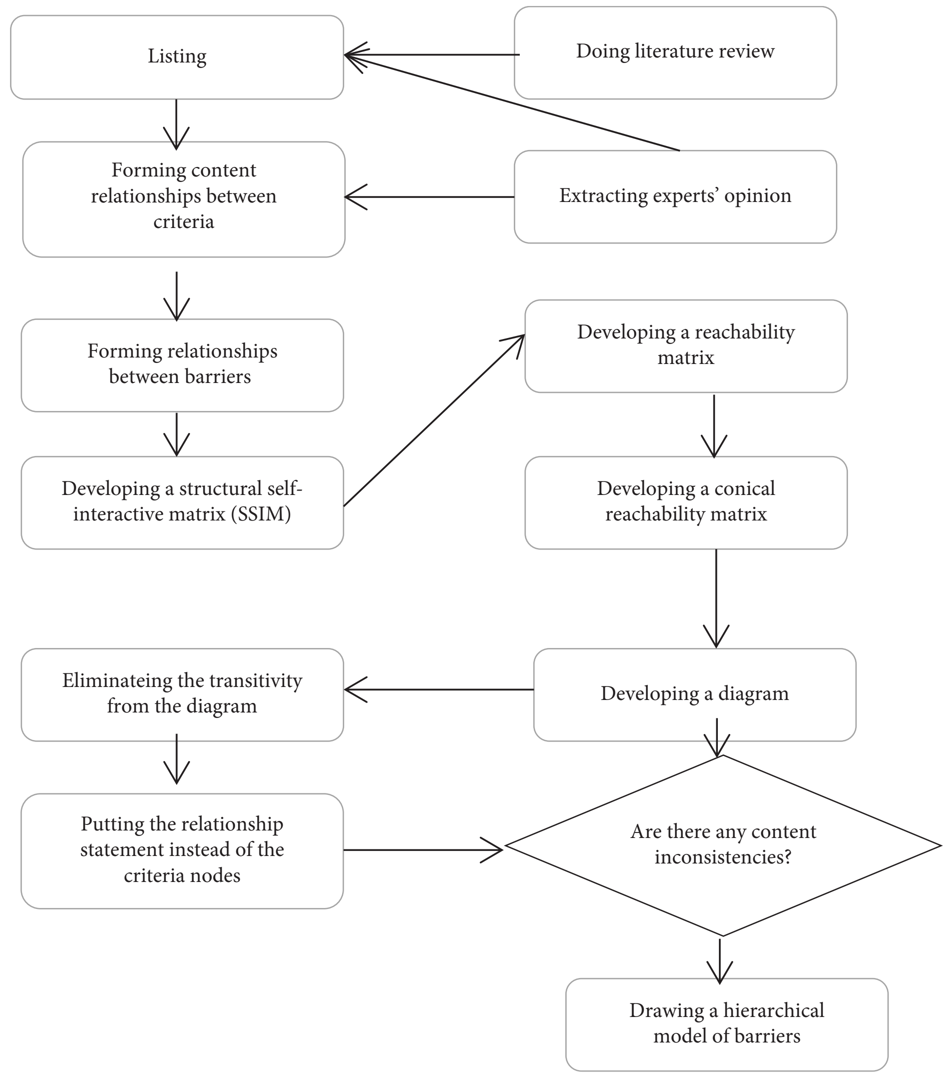

Figure 4: Steps of the interpretive ranking process method (source: author).

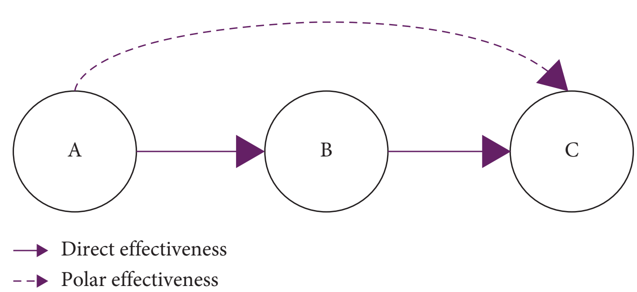

Figure 5: The process of the propositions' direct and polar effectiveness in the interpretive matrix (source: author).

The following relations ("I" is the identity matrix) should be used to generate the relation matrix, or initial reachability matrix, before gaining the final reachability matrix:

$$M = D + I$$
$$M^* = M^k = M^{k+1}, \quad k > 1. \tag{10}$$

Each component in huge complicated systems is meant to be accessed from within. As a result, the system's final matrix's primary diagonal entries are all always 1. To obtain the final matrix, the identity matrix is consequently added to the initial reachability matrix. One of the final matrix's characteristics is as follows:

$$M^2 = M. \tag{11}$$

The gained matrix should be the final matrix, and the final matrix should be in exponentiation to the point where the emergency situation arises. The first line's number of 1s indicates the lines or impacts that the first criterion has produced. The number of 1s in the first column indicates the weight that the first criterion has been given. Source is the element that has an impact on all system elements but is unaffected by any other element.

3.4. Antecedent and Succedent Set. The final matrix structure as well as the system design are significantly influenced by the two separate antecedent sets (A) and the succedent or reachable set (R) that each of the system components (criteria) has. The criteria that lead to or have an impact on each criterion are included in the antecedent set of that criterion. In other words, they are placed in front of the criteria in the column that is related to criterion number 1, which is an antecedent set on that column criterion. For instance, if criterion 1 is affected by criterion 2, 3, and 4, then these criteria make up the antecedent set of criterion 1. The succedent set, on the other hand, displays the criteria that a criterion or system component has an impact on. For instance, if criterion 1 influences criterion 2, 3, 4, and 5, then criterion 2, 3, 4, and 5 are the set of criteria that follow criterion 1. The accessible set is another name for the succession set.

3.5. Criterion Leveling. The criteria are leveled after identifying the reachable set, the antecedent set, and the standard set for each of the criteria. A standard-setting is obtained by acquiring the commonality of the attainable and preceding settings. First-level precedence is given to criteria whose formal setting matches the reachability set. By deleting these requirements and then doing it again for the other needs, the story of all requirements is revealed. The ISM diagram is created using the final matrix and the determined levels. This rule is repeated for each class to determine it (C is the set of criteria).

$$R\left(C_j\right) \cap A\left(C_j\right) = R\left(C_j\right), \quad \forall C_j \in C. \tag{12}$$

3.6. Clustering of Criteria. It is necessary to calculate each driving force and dependence component in order to categorize the reachability matrix's criteria. The number of criteria that the connected criterion affects is what motivates an element or criterion. Dependency power is the total number of criteria that influence and ultimately lead to the linked criterion. In the matrix study of the multiplier impact of categorization mutual application cross-reference, these driving forces and dependencies are utilized (MICMAC). The four categories of the criteria are autonomous, dependent, connective, and independent (driving criterion). The goal of matrix analysis is to analyze the driving force, power, and dependency of the variables through the multiplier influence of their applied cross-references. Four clusters are used to group variables (Figure 6). The autonomous criteria, which have a weak driving force and dependency, are included in the first cluster. The system, which has little connectivity to other system components, is almost completely separated from these criteria. They may have significant relationships, of course. Dependent criteria, which have a strong dependency power but a weak driving force, are included in the second cluster. Hybrid criteria, which have a strong driving force as well as a strong reliance power, are part of the third cluster. These criteria are in fact unstable because any change to them will have an impact on other criteria or provide feedback to them. Independent criteria, which have great driving power and low dependent power, are included in the fourth cluster. As you can see, a criterion with high driving force is called a key criterion and is inserted in the dependent or hybrid variables.

3.7. Statistical Population. 15 university-level specialists and experts in industrial management who have a specialized and scientific approach by engaging in scientific research in a related subject make up the statistical population in the qualitative portion. They were chosen using a homogenous sample technique since the participants in this section were expected to have a theoretical understanding of the research issue. Additionally, studies from websites such as University Jihad (SID) in Iran, Iranian Publications Database (MAGIRAN), Islamic Computer Science Research Center (NOORSOFR) of Iran, the international reference for the most recent articles in the world (Sciencedirect), Emerald Reference (Emeraldinsight), and OnlineLierary were used to determine components (functioning of competitive supply chain pricing) and indicators (social resemblance) in this section based on the meta-synthesis. Twenty managers from knowledge-based organizations in the oil sector were utilized in the second phase to complete the matrix checklists in accordance with the nature of the study. This procedure is known as the interpretative ranking process (IRP). It should be noted that the interpretive ranking process (TISM-IRP) is finite in sample size and is consistent with studies such as Sushil [44] and Chithambaranathan et al. [41] because it is an analysis based on matrix analysis and analysis in operations that should be performed by participants based on a specific criterion such as experience or expertise.

3.8. Findings. There is no predetermined and definitive list for components of functioning of competitive supply chain pricing associated with propositions of social responsibility, and there is no definite possibility for identifying and limiting all features related to the research objective in a specific set with clear and distinctive distinctions in the form of the conducted research. However, the findings of this research show that the participants in this study, according to the researcher's initial description of the subject for them, were able to gain an excellent understanding to create matrix checklists to identify the research's elements, markers, and features and to ascertain their dimensions. As a result, the qualitative analysis portion will present a meta-synthesis, and the quantitative area will present an interpretive ranking procedure.

Driving power					
1					
2		Area 4		Area 3	
...					
n-1					
n		Area 1		Area 2	
Dependency power	1	2	...	n-1	n

Figure 6: Classification of criteria using driving power and dependency power (source: author).

3.8.1. Findings of Meta-Synthesis. One of the methods of analysis in the qualitative section is meta-synthesis. Meta-synthesis analysis is a qualitative research method. Thinkers in practice have come to the conclusion that it is not possible to a large extent to know and master all aspects of a field and to be up-to-date in this field due to the development of research in various fields of science and the scientific community being confronted with an explosion of information; therefore, conducting synthetic research, which puts the extract of a study conducted on this particular subject systematically and scientifically before researchers, has become increasingly widespread. To perform a meta-analysis, it is necessary first to determine similar research with its content and nature. Hence, in this section, an effort was made to select relevant studies by searching the databases of reputable foreign journals and scientific and research journals. Following this, the analytical processes of this section were used to identify and determine the components and propositions related to the research topic. Analyzing comparable studies took place from 2017 to 2021. In other words, research relevant to the research objective was selected and searched for using domestic and international research databases and references (Figure 7).

As seen in Figure 2, all 51 sources that were first discovered after going through various levels of screening in terms of content, title, and analysis, finally, 26 types of research proportional to the content, identification, and analytical procedures of this research were selected, 16 types of research were related to social responsibility propositions, and ten kinds of research were related to the components of operation of supply chain pricing competition. To define the most efficient functioning of a competitive supply chain pricing system based on social responsibility aspects in the form of score checklists, concepts should be divided based on elements and propositions at this stage. In actuality, through the criteria of critical evaluation based on ten criteria of research objectives, the logic of the research method, research design, sampling, data collection, reflectivity, the accuracy of the analysis, theoretical and transparent expression of findings, and the value of research, the propositions of social responsibility dimensions are determined in Table 3 and the components of the functioning of competitive supply chain pricing are defined in Table 4.

3.8.2. Identification of Social Responsibility Propositions (X). Social responsibility claims are marked in this section with the symbol (R) in accordance with the justifications provided. Table 1 analyzes how to evaluate requests using a 50-point scale with scores ranging from 1 to 5 based on the 10 factors mentioned.

The scores provided based on the mode index showed four types of research of Famiyeh et al. [48], Drugan [52], Haghir et al. [56], and Atani et al. [60] were eliminated because they only received 30 out of a possible 50 points. The researchers who score 30 or higher are accepted, per criteria for the score adequacy of this analysis. They were therefore not included in the research. The concepts of social responsibility are extracted in the paragraphs that follow. As a result, the multidimensional social responsibility recommendations are determined using the scoring methodology below. The names of the approved research researchers are listed in the row of each table after each subcriteria has been extracted from the accepted articles and written in the table's column. The sign "☑" is added based on how each researcher used the subcriteria listed in the table's column. The scores of each researcher are then summed up in the subcriteria column, and research proposals with scores higher than the research average are chosen.

Based on this analysis, it was discovered that the seven propositions with the highest frequency are those related to the environment, the economy, society, ethics, voluntarism, and institutional/legal dimensions. They are therefore examined in this study as the primary social responsibility dimensions. Each of the recognized propositions is defined in accordance with Table 5 in the next section once the theoretical underpinnings of the accepted study have been examined (Table 3).

3.8.3. Identifying the Components of Functioning of Competitive Supply Chain Pricing (T). The operation of competitive supply chain pricing is established using the same process as in the phases above and in this section. The operation of the competitive supply chain pricing with the symbol (T) is identified in this section in accordance with the justifications provided. According to the ten criteria listed, Table 6 examines how to rate the components using a 50-point scale with values ranging from 1 to 5.

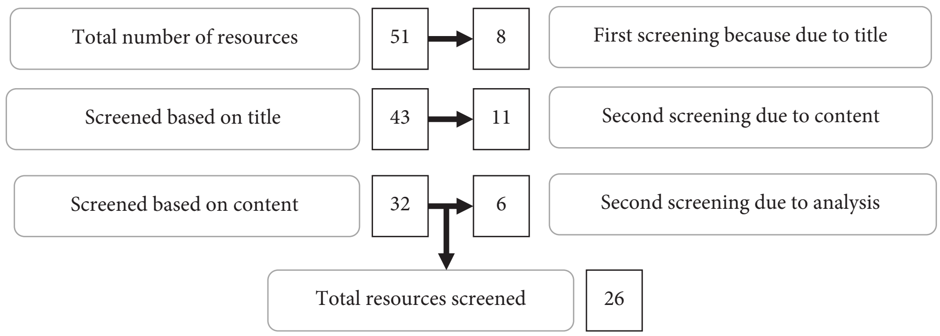

Figure 7: Screening of initial research (source: author).

Out of a total of 10 initial types of study, two types of research by Farham-Nia and Ghaffari-Hadigheh [61] and Mahmoudi et al. [68] were removed because they received fewer than 30 out of 50 points, according to the scores provided based on the mode index. The researchers who score 30 or higher are accepted, per criteria for the score adequacy of this analysis. They were therefore not included in the research. The research hypotheses are then derived. Accordingly, the elements associated to competitive supply chain pricing are determined using the following scoring methodology. The names of the approved research researchers are listed in the row of each table after each subcriteria has been extracted from the accepted articles and written in the table's column. The symbol "☑" is added based on how each researcher used the subcriteria listed in the table's column. After that, the scores of each researcher are summed up in the subcriteria column, and scores that are higher than the researches' average are chosen as the research components (Table 7).

Based on this investigation, it was discovered that the three elements that make up competitive supply chain pricing that is based on rivals, competitive supply chain pricing that is based on operations, and competitive supply chain pricing that is based on customer value occur most frequently. After examining the theoretical underpinnings of the accepted studies, Table 4 defines each of the identified components in accordance with Table 8.

3.9. Interpretive Ranking Process (IRP). The procedures associated with this study are carried out in light of the fact that the elements of the operation of competitive supply chain pricing (R) and the social responsibility propositions (T) have been determined based on the efficacy of row "i" on column "j" or vice versa. Therefore, the direct, symmetrical, or indirect relation should first be taken into account in line with the explanations in order to develop interactive matrices. Instead, the following is how the matrix questionnaire is determined:

The elements of competitive supply chain pricing with social responsibility are now shown in the Table 9 to establish a reciprocal interpretation.

Each social responsibility proposition's level of efficacy is assessed in light of the findings in this section. The pairwise comparison score form, which is employed in the sections that follow in the matrix prioritization analysis, served as the foundation for this evaluation's scoring methodology.

The social size is the basis for the effectiveness of the environmental dimension of corporate social responsibility, according to the table that was presented as part of the effectiveness of the relationships. For instance, the paired comparison at the level of social responsibility dimensions T, the environmental dimension $T1$, and the social dimension $T2$ are related as the effect of ji. Table 9 compares the study hypotheses pairwise to create the structural self-interaction matrix (SSIM). For pairwise comparisons, all elements from $(i+1)$ th to nth were compared with the i-th index in pairs. For each relationship, a yes or no response is supplied, and if a positive response is given, a justification is offered. In this instance, a scientific, interpretative logical foundation for pairwise relationships' interpretive logic is offered. The links are entered as a reachability matrix in this stage, denoted by the values "1" or "0," as shown in Table 9. The cells with the option "Yes" are numbered one in Table 10, while the cells with the option "No" are numbered 0. The structural self-interaction matrix is transformed into a zero and one two-value matrix to create this matrix (Table 11).

In order to generate the interaction reachability matrix, scores are formed in this stage based on the interaction of the compared indicators.

Considering that the level of direct and transferable effectiveness of the research propositions is determined, the score percentages of the total level of effects are defined in the next step, which is presented in Table 12.

According to the findings, only 17.07% of the social responsibility claims made by knowledge-based enterprises in the provision of petroleum products have a transferable effect, while 53.65% are directly related. The percentage related to the energy of the ethical dimension of social responsibility ($T6$) is higher than other propositions based on the pairwise scale between the research propositions, meaning that the ethical dimension is where knowledge-based companies place the most emphasis on social responsibility, which can reflect the committed functions of businesses towards society. The most effective aspect of the functioning of a competitive supply chain pricing is therefore determined based on the ethical dimension of social responsibility in knowledge-based companies in the field of supply of oil products, according to Tables 9 and 13, and given the influential role of the moral size of social

Table 3: Propositions of social responsibility (source: author).

Components	Definitions
Environmental dimension	The environmental dimension is one of the most critical dimensions of social responsibility towards society and the future, which examines the approaches of institutions and organizations towards the development of environmental sustainability. This dimension includes cautious strategies for preventing or minimizing adverse effects, supporting measures and initiatives that promote more environmental responsibilities, and developing and disseminating desirable and environmentally friendly technologies. [50]
Social dimension	The social dimension has a broader function than other dimensions of social responsibility. It includes the firm's performance processes towards the community and dynamic social relationships with stakeholders such as information provision, transparency in performances, and flexible organizational structures. It generally explores the relationships of an institution and organization with the environment and society. Some of the indicators of this dimension can include respect for human resource rights, education, and development, and assistance to specialties related to social programs. [51]
Economic dimension	The economic dimension includes maintaining benefits for companies. It investigates the effect of financial aspects and profitability of an institution and organization on collectivist social interests and its effect on the economy as a whole [57]
Beneficiary dimension	This dimension refers to the commitment of institutions and organizations in adhering to the needs of stakeholders and is, in fact, a set of management activities that ensure the maximum positive effect of the company's operations on society. It is also a set of processes that somehow meet or achieve more than the rules, ethics, business, and general expectations of society from business [55]
Voluntary dimension	This dimension of voluntary activities such as promoting responsible customs and norms, doing charity work, meeting the social needs of the poor, holding nongovernmental organizations and participating in philanthropic activities, etc., all fall into the category of activities of this dimension that can also help the company perform its competitive operations effectively [46]
Ethical dimension	This dimension refers to the development of professional ethics procedures in business and the existence of observance of spirituality and principles such as work conscience to respect the rights of stakeholders. Organizations and institutions committed to social responsibility will always strive to increase the level of social confidence and belief in accountability and responsibility for the interests of others by developing committed actions against the interests of stakeholders [47]
Institutional dimension	An institutional dimension is also a modest approach to the legitimacy of social laws and standards, which includes the level of adherence of organizations to the laws and institutional requirements by the institutions that oversee the performance of an organization. In other words, it is a kind of promotion of the rule of law and respect for the requirements formulated by higher institutions that can increase the level of culture of respect for directions at the macro level and increase the level of civilization of respect for civil and individual rights at a more detailed level [51]

responsibility in knowledge-based companies in the field of supply of oil products (Table 14).

As it can be seen, this proposition has the highest level of transferability since the functioning of competitive supply chain pricing based on customer value has a higher level of transferability than the other two components. This finding demonstrates that, although affecting other factors, the ethical dimension ($T6$) in the social responsibility of knowledge-based enterprises in the provision of oil products is seen as the most important aspect in developing a competitive supply chain pricing model based on customer value ($R3$). Based on the results, the ranks for interpretative ranking procedures (IRP) are displayed in the table below (Table 15).

The outcomes demonstrate that the competitive supply chain pricing function based on the social responsibility claims of knowledge-based enterprises in the oil field is most closely related to the operation of competitive supply chain pricing based on customer value "R3". The most effective component of a competitive supply chain pricing, however, has a dependence level that, when calculated as the row sum, shows that it is influenced by other components. As a result, this dependence level has a higher correlation with the functioning of a competitive supply chain pricing being based on competitors than its other two dimensions. The collection of output, input indicators, and standard elements are chosen to construct the hierarchical model "TISM," i.e., the structural layer model, after identifying which parts of

Table 4: Components of functioning of competitive supply chain pricing, (source: author).

Functioning of competitive supply chain pricing	Definitions
Functioning of competitive supply chain pricing based on competitors	In many markets, supply chain pricing will be based on competitors' prices. Companies continuously evaluate their competitors' pricing process to achieve supply chain channels that, while reducing costs, provide competitive advantages in the market for them. In other words, it is a kind of evaluation that compares the products that can be offered with the consequences of other competitors so that the customers of the target market feel more favorable about the value of the product purchased. Usually, pricing close to competitors' prices can be a reliable strategy to retain customers [62]
Functioning of competitive supply chain pricing based on operations	The functioning of competitive supply chain pricing based on operations is a method that aims to optimize production capacity to achieve operational efficiency or to match the supply and demand of the competitive supply chain through various prices. In some cases, prices may be adjusted to the supply market and may be determined based on operational strategies [64]
Functioning of competitive supply chain pricing based on customer value	The functioning of competitive supply chain pricing based on value is a method in which a company seeks to balance market value with the mental weight of its customers. The purpose of competitive supply chain pricing is to strengthen the company's overall positioning strategy in customers' minds in terms of image and quality of products [65]

Table 5: The process of critical analysis of screened researches (source: author).

Research position	Papers	Critical evaluation criteria										
		Research objectives	The logic of the research method	Research design	Sampling	Data collection	Reflectivity	Ethical considerations	Accuracy of analysis	Theoretical and clear expression of findings	Value of research	Total
International research	Adegbite et al. [45]	3	5	4	3	3	3	4	5	4	4	38
	Min et al. [46]	4	4	4	4	4	4	4	3	4	4	39
	Arrigoni [47]	3	4	4	4	3	4	3	4	4	4	37
	Famiyeh et al. [48]	2	2	3	3	3	2	3	3	3	3	27
	Sharabati [49]	4	4	3	4	2	3	4	4	4	4	36
	Arli and Tjiptono [50]	4	3	3	4	3	3	3	4	4	4	31
	Amos [51]	4	5	5	3	4	3	3	3	4	4	38
	Drugan [52]	2	3	2	2	3	2	2	2	2	3	23
	Beal and Neesham [53]	3	4	3	4	3	3	4	3	3	4	34
Domestic research	Akbari et al. [54]	2	3	3	3	4	3	3	3	4	4	32
	Ghafourian Shagerdi et al. [55]	4	5	4	4	3	4	4	3	5	4	39
	Baradaran Haghir et al. [56]	3	3	3	2	2	3	3	2	2	3	26
	Noorbakhsh and Akbarian [57]	4	3	4	4	4	4	4	4	4	4	39
	Fayazi Azad et al. [58]	4	4	4	3	4	3	3	4	3	4	36
	Seyed Javadin et al. [59]	3	3	3	3	4	4	3	3	4	4	34
	Atani et al. [60]	3	2	2	3	2	3	2	3	3	3	27

Table 6: Process of determining social responsibility dimensions' frequency.

Research position	Researchers	Environmental dimension	Economic dimension	Organizational dimension	Social dimension	Ethical dimension	Cultural dimension	Voluntary dimension	International dimension	Ethical dimension	Institutional/legal dimension
International research	Adegbite et al. [45]	—	✓	—	✓	—	—	—	—	✓	—
	Min et al. [46]	✓	—	✓	✓	✓	—	—	✓	—	—
	Arrigoni [47]	✓	✓	—	✓	—	✓	✓	—	✓	—
	Sharabati [49]	✓	—	—	✓	✓	—	✓	—	✓	✓
	Arli and Tjiptono [50]	—	✓	✓	—	—	✓	—	—	✓	✓
	Amos [51]	✓	—	—	—	✓	—	✓	—	—	✓
	Beal and Neesham [53]	—	✓	✓	✓	✓	—	✓	—	—	✓
Domestic research	Akbari et al. [54]	✓	—	—	✓	✓	—	—	—	✓	✓
	Ghafourian Shagerdi et al. [55]	✓	—	—	✓	—	—	✓	—	—	—
	Noorbakhsh and Akbarian [57]	—	—	—	—	—	✓	—	—	✓	—
	Fayazi Azad et al. [58]	✓	✓	—	✓	✓	—	✓	✓	—	✓
	Seyed Javadin et al. [59]	✓	✓	—	✓	✓	—	✓	—	—	✓
	Total	**8**	**6**	**3**	**9**	**7**	**3**	**7**	**2**	**6**	**7**

The numbers in the Total row show that how many studies of 12 studies, has focused on each dimension, in our opinion as it is not a statistical issue related to a population, significance does not make sense to be addressed.

Table 7: Process of determining the main components of the research (source: author).

Position	Researchers	Customer interaction dynamics	Competitor-based pricing	Income-based pricing	Value-based pricing	Operation-based pricing	Pricing based on psychological characteristics
International research	Chen et al. [62]	—	✓	—	—	✓	—
	TM and Mahanty [63]	—	—	✓	✓	✓	✓
	Kalaitzi et al. [64]	✓	—	✓	—	—	—
	Pang and Tan [65]	—	✓	—	✓	✓	✓
	Li and Yi [66]	—	✓	—	✓	✓	—
Domestic	Ranjbar and Sahebi [67]	✓	✓	—	—	—	—
	Jamali and Karimi Asl [69]	—	—	—	✓	✓	—
	Rahmani et al. [70]	—	✓	—	✓	✓	—
	Total	**2**	**5**	2	**5**	**6**	**2**

The numbers in the Total row show that how many studies of 8 studies, has focused on each dimension, in our opinion as it is not a statistical issue related to a population, significance does not make sense to be addressed.

Table 8: The critical analysis process of screened researches (source: author).

Research position	Paper	Critical evaluation criteria										
		Research objectives	The logic of the research method	Research design	Sampling	Data collection	Reflectivity	Ethical considerations	Accuracy of analysis	Theoretical and clear expression of findings	Value of research	Total
International research	Farham-Nia and Ghaffari-Hadigheh [61]	2	3	2	1	2	3	2	2	3	2	32
	Chen et al. [62]	3	4	4	4	3	4	4	4	3	4	37
	TM and Mahanty [63]	4	5	5	3	4	3	3	3	4	4	38
	Kalaitzi et al. [64]	4	3	4	3	4	3	3	4	3	3	33
	Pang and Tan [65]	4	3	3	4	5	5	4	4	3	4	39
	Li and Yi [66]	4	4	5	4	3	3	4	3	3	4	37
Domestic research	Ranjbar and Sahebi [67]	4	3	4	5	3	4	3	3	3	3	35
	Mahmoudi et al. [68]	2	2	1	2	3	2	3	2	3	2	22
	Jamali and Karimi Asl [69]	3	4	4	4	4	4	3	4	5	5	40
	Rahmani et al. [70]	4	3	4	3	4	4	3	4	4	4	35

Table 9: Interpretive analysis on the reciprocal matrix of functioning of competitive supply chain pricing with social responsibility (source: author).

			T1	T2	T3	T4	T5	T6	T7
Components	Competitive supply chain pricing functions	R1			Economic dimension as the basis for the functioning of competitor-based pricing	Beneficiary dimensions as the basis for the functioning of competitor-based pricing		Ethical dimension as the basis for the functioning of competitor-based pricing	Institutional dimension as the basis for the functioning of competitor-based pricing
		R2	Environmental dimension as the basis for the functioning of operation-based pricing		Economic dimension as the basis for the functioning of operation-based pricing				Institutional dimension as the basis for the functioning of operation-based pricing
		R3	Environmental dimension as the basis for the functioning of value-based pricing	Social dimension as the basis for the functioning of value-based pricing		Beneficiary dimension as the basis for the functioning of value-based pricing	Voluntary dimension as the basis for the functioning of value-based pricing	Ethical dimension as the basis for the functioning of value-based pricing	
						Investor's risks Propositions			

Table 10: Reciprocal matrix of functioning of competitive supply chain pricing with social responsibility (source: author).

Propositions Components	A/B	Environmental dimension $T1$	Social dimension $T2$	Economic dimension $T3$	Beneficiary dimension $T4$	Voluntary dimension $T5$	Ethical dimension $T6$	Institutional dimension $T7$	
Functioning of competitive supply chain pricing based on competitors	$R1$	0	0	1	1	0	1	1	
Functioning of competitive supply chain pricing based on operations	$R2$	1	0	1	0	0	0	1	Judicial Components
Functioning of competitive supply chain pricing based on customer value	$R3$	1	1	0	1	1	1	1	
					Investors' risks Propositions				

Table 11: Reachability matrix (source: author).

Social responsibility dimensions			Propositions						
			Environmental dimension $T1$	Social dimension $T2$	Economic dimension $T3$	Beneficiary dimension $T4$	Voluntary dimension $T5$	Ethical dimension $T6$	Institutional dimension $T7$
Propositions	Environmental dimension	$T1$	1	0	0	1	0	0	0
	Social dimension	$T2$	1	1	0	1	0	0	0
	Economic dimension	$T3$	0	0	1	0	0	0	0
	Beneficiary dimension	$T4$	0	0	0	1	1	0	0
	Voluntary dimension	$T5$	1	1	0	0	1	0	0
	Ethical dimension	$T6$	1	1	0	1	1	1	0
	Institutional dimension	$T7$	0	1	1	0	1	1	1

Table 12: Score percentages for the level of effectiveness of social responsibility propositions of knowledge-based oil companies (source: author).

Reference variable			Direct effectiveness	Transferable effectiveness	Interpretive effectiveness	Overall effectiveness	Percentage of interpretive effectiveness
Propositions	Environmental dimension	$T1$	2	0	2	4	9.75
	Social dimension	$T2$	3	1	1	5	12.19
	Economic dimension	$T3$	1	3	2	6	14.63
	Beneficiary dimension	$T4$	2	0	2	4	9.75
	Voluntary dimension	$T5$	3	1	1	5	12.19
	Ethical dimension	$T6$	5	2	2	9	21.98
	Institutional dimension	$T7$	6	0	2	8	19.51
Total			22	7	12	41	
Percentage			53.65	17.07	29.28		

Table 13: Pairwise comparison of social responsibility propositions (source: author).

No	Pairwise comparison	Yes/No	Description of the effect
☐$T1$ Pairwise comparison in the environmental dimension			
1	$T1-T2$	Yes ☐ No ☒	
2	$T2-T1$	Yes ☒ No ☐	Social dimension as the basis for the effectiveness of the environmental dimension of corporate social responsibility
3	$T1-T3$	Yes ☐ No ☒	
4	$T3-T1$	Yes ☐ No ☒	
5	$T1-T4$	Yes ☒ No ☐	Environmental dimension as the basis for the effectiveness of the beneficiary dimension of corporate social responsibility
6	$T4-T1$	Yes ☐ No ☒	
7	$T1-T5$	Yes ☐ No ☒	
8	$T5-T1$	Yes ☒ No ☐	Voluntary dimension as the basis for the effectiveness of the environmental dimension of corporate social responsibility
9	$T1-T6$	Yes ☐ No ☒	

Table 13: Continued.

No	Pairwise comparison	Yes/No	Description of the effect
10	$T6-T1$	Yes ☒ No ☐	Ethical dimension as the basis for the effectiveness of the environmental dimension of corporate social responsibility
11	$T1-T7$	Yes ☐ No ☒	
12	$T7-T1$	Yes ☐ No ☒	

Table 14: Investigating the interpretive effectiveness of the functioning of competitive supply chain pricing (source: author).

Functioning of competitive supply chain pricing			Components		
			$R1$	$R2$	$R3$
Components	Functioning of competitive supply chain pricing based on competitors	$R1$	1	1	1*
	Functioning of competitive supply chain pricing based on operations	$R2$	1	1	1*
	Functioning of competitive supply chain pricing based on customer value	$R3$	1	1*	1*

Table 15: Prioritizing the level of dependency and influence of competitive supply chain pricing function (source: author).

Functioning of competitive supply chain pricing			Components			Evaluation criteria		
			$R1$	$R2$	$R3$	Dependency level D	D-B difference	Rank
Components	Functioning of competitive supply chain pricing based on competitors	$R1$	—	**1**	**1**	**2**	**−2**	**3**
	Functioning of competitive supply chain pricing based on operations	$R2$	**1**	—	**2**	**3**	**0**	**2**
	Functioning of competitive supply chain pricing based on customer value	$R3$	**3**	**2**	—	**5**	**2**	**1**
	Influence level B		**4**	**3**	**4**	**10**		

Table 16: Set of output, input indicators, and common elements of propositions (source: author).

Propositions	Abbreviation	Output proposition	Input proposition	Common elements	Level
Environmental dimension	$T1$	1, 4	1, 2, 3, 5, 6	1	Second level
Social dimension	$T2$	1, 2, 4, 7	2, 5, 6, 7	2, 7	Third level
Economic dimension	$T3$	1, 3, 4, 6	3, 6, 7	3, 6	Fourth level
Beneficiary dimension	$T4$	4	1, 2, 3, 4, 6, 7	4	First level
Voluntary dimension	$T5$	1, 2, 5, 7	4, 5, 6, 7	5, 7	Fifth level
Ethical dimension	$T6$	1, 2, 3, 4, 5, 6, 7	1, 6, 7	1, 6, 7	Sixth level
Institutional dimension	$T7$	2, 3, 4, 5, 6, 7	2, 5, 6, 7	2, 5, 6, 7	Fifth level

the research in this section are the most effective by consulting Tables 9, 10, 13, and 16.

Based on the results, it was found that the effective layers of the dimensions of social responsibility in knowledge-based companies in the oil field have six levels, so that the beneficiary dimension is in the first level. The least practical size of social responsibility and the most effective component is related to the ethical size of social responsibility in knowledge-based companies in the oil field. According to the explanations given, a conical matrix is provided in Figure 8 to show the effectiveness of the dimensions of social responsibility in Figure 4 as follows:

As can be seen, the two propositions of credit risk ($B6$) and inflationary risk ($B6$) are the two bases of risk in oil companies' stock investments that investors are more likely to face, as they are in the last level of Figure 4, i.e., the fourth level. Finally, now that the most influential risk propositions of oil companies' investors' weights are given to each of the research components, namely, the dimensions of the judicial accounting paradigm. In other words, this section seeks to determine the most critical size of judicial accounting by determining the effectiveness level of risk propositions of oil companies' investors (Table 17).

The rankings in choosing the most useful components of the research are similar both interpretively and by weight when compared to the straightforward interpretive prioritization process in Table 18 and the interpretive prioritization in the table above on the operation of competitive supply chain pricing. The following table provides a comparison of these findings (Table 19).

In reality, it should be noted that the high weight of each component in the analysis of the interpretative prioritizing

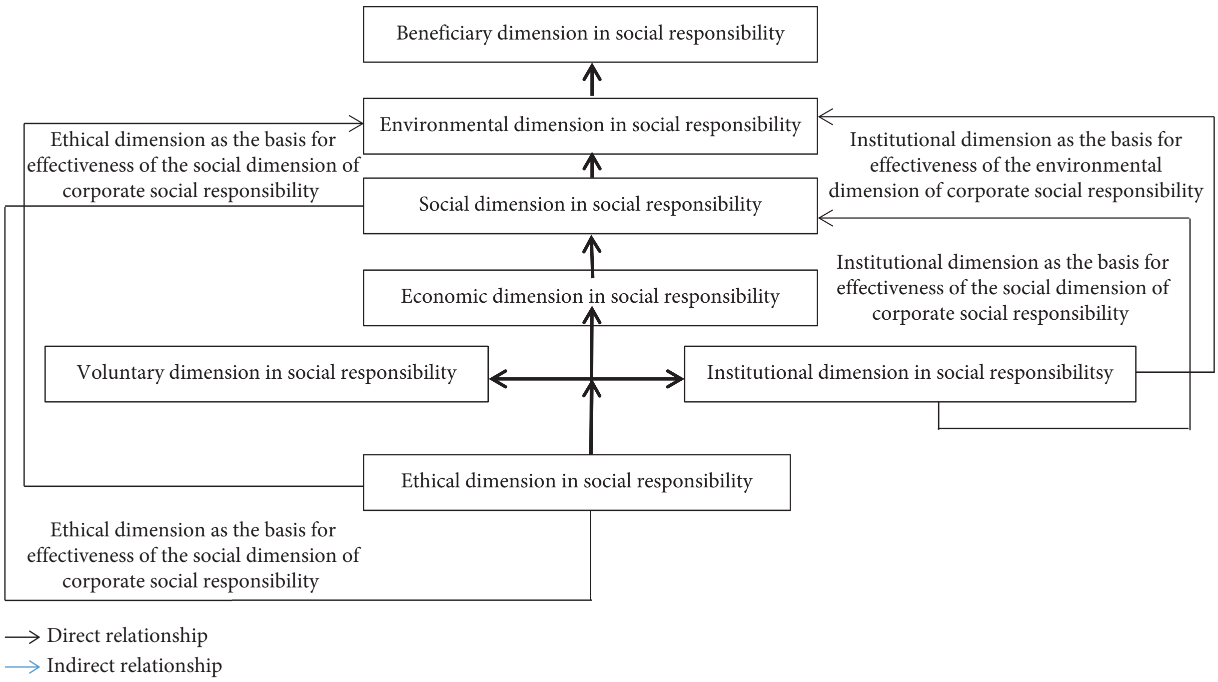

FIGURE 8: Classifying the dimensions of social responsibility of knowledge-based oil companies (source: author).

TABLE 17: Selection of the most important component of functioning of competitive supply chain pricing (source: author).

Functioning of competitive supply chain pricing		*R*1	*R*2	*R*3	Dependency level D	D-B difference	Rank
Functioning of competitive supply chain pricing based on competitors	*R*1	—	0.68	1.09	1.77	−1.24	3
Functioning of competitive supply chain pricing based on operations	*R*2	0.54	—	2.13	2.67	−0.66	2
Functioning of competitive supply chain pricing based on customer value	*R*3	1.93	2.65	—	4.58	1.36	1
Influence level B		3.01	3.33	3.22			

TABLE 18: Reachability matrix in terms of transferability of the relationship between the propositions (source: author).

Social responsibility dimensions			Propositions						
			Environmental *T*1	Social *T*2	Economic *T*3	Beneficiary *T*4	Voluntary *T*5	Ethical *T*6	Institutional *T*7
Propositions	Environmental	*T*1	1	0	0	1	0	0	0
	Social	*T*2	1	1	0	1	0	0	1*
	Economic	*T*3	1*	0	1	1*	0	1*	0
	Beneficiary	*T*4	0	0	0	1	1	0	0
	Voluntary	*T*5	1	1	0	0	1	0	1*
	Ethical	*T*6	1	1	1*	1	1	1	1*
	Institutional	*T*7	0	1	1	1	1	1	1
Effect determination process			Direct effect			Transferable effect			

TABLE 19: Comparative rankings for the simple and weighted interpretive prioritization process (source: author).

	Functioning of competitive supply chain pricing based on competitors *R*1	Functioning of competitive supply chain pricing based on operations *R*2	Functioning of competitive supply chain pricing based on customer value* *R*3
Weighted interpretive ranking	3	2	1
Simple interpretive ranking	3	2	1

process (IRP) weights denotes that component's higher level of importance in the target population. Based on this finding, it should be noted that in knowledge-based oil companies, the function of competitive supply chain pricing based on customer value, which has the highest level of priority among the components of competitive supply chain pricing function, is the most effective under the ethical dimension of social responsibility.

4. Discussion and Conclusion

This study is set out to determine how competitive supply chain pricing based on social responsibility factors functions is best for oil products produced by knowledge-based businesses. Based on the research findings, 3 competitive supply chain pricing functions and 7 propositions linked to the dimensions of social responsibility in knowledge-based enterprises in the oil field were found in response to the study's first and second questions. According to the findings, the proposal of the ethical dimension in social responsibility, which can produce competitive supply chain pricing functions based on value, was discovered to be the most probable dimension of social responsibility in knowledge-based enterprises in the oil field. In fact, the ethical dimension, which refers to the development of professional ethics procedures in line with the nature of knowledge-based companies based on the development of knowledge-based products, creates corporate social responsibility mechanisms and makes them resolutely accountable to stakeholders while strengthening social beliefs regarding their performance to advance the national and domestic economy more thoroughly. Simply put, since oil is regarded as a strategic product in our nation's economy, emphasizing development-oriented dimensions in the field of oil and its derivatives, along with upholding ethical principles, fosters prosperity, and sustainable economic development by increasing the trust and confidence of businesses using such products as primary materials or as raw materials used. On the other hand, based on the third question of the research, it was found that under the ethical dimension of social responsibility, competitive supply chain pricing processes are based on customer values and according to the strategic relationship among the company and the economy and regional and global partners, maintaining values is a key pricing factor to develop interactions. In fact, this price function seeks to entice customers' mentalities toward using the goods of domestic and Iranian knowledge-based businesses in order to win their trust and confidence and thereby provide value for their clients. Knowledge-based businesses will be able to strategically assess their competitive position in this situation, plan for potential future situations, and promote their products to meet the needs of their consumers based on value-based competitive supply chain pricing. The obtained result is consistent with the researches of TM and Mahanty [63], Pang and Tan [65], Li and Yi [66], and Jamali et al. [69]. Given in the results, in the first step for success, knowledge-based companies are recommended to consider the priorities of professional ethics in addition to knowledge in order to be able to gaining the trust of customers, by understanding their functional nature in the country's developing economy. In this situation, the pricing process based on the creation of comprehensive values for customers can help to increase the company's competitive position and make these companies to be at the first level of strategic interactions with companies that use petroleum products. Finally, as the results of this study may not be completely generalized to other populations, the researchers are suggested to apply the same study in other communities with diverse products.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Hybrid Power Generation Supply Chain Financing and Purchasing Strategies with Option Hedging against Disruption

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Environmental pollution has stimulated cleaner and sustainable energy (CSE) resource consumption which fuels low-carbon electric-power growth. This consumption is particularly affected by two factors. One of them is the power grid's capital size in the electricity supply chain (ESC) and the other is the carbon emission reduction level elasticity of electricity consumption. Further, the financial strategy directly exerts quantifiable influence on one of the factors of capital size, while the procurement strategy plays a role in another factor. However, the impact of strategic behavior on all participants in the ESC remains unexplored. Thus, we construct a game model for the ESC consisting of two heterogeneous power plants and a strategic power grid with financial constraints, in order to analyze the purchasing and financing strategies for low-carbon electric-power consumption and examine the profit scenario from the credit and option hedging. We find that for the power grid, high self-owned funds level or affluent credit line encourages procurement. And when considering the power grid funds are uniformly distributed on or are constant, this funds property variation surely imposes influence on the wind electricity purchases. We find price elasticity of demand shows monotonic on the purchase when the power grid funds are constant but not necessarily when funds are uniformly distributed. The two power plants pursue the most favorable scenario for profit-maximizing by means of credit interest rate. Whether the power plants increase the financial credit interest is contingent upon option portfolios, the grid's fund property, and wind yield conditions. We also find whether the relations between the two power plants are competitive or complementary depending on the wind yield rate. Numerical study shows that when the power grid funds are uniformly distributed, executing the double option seems to be the most profitable choice for the power grid and the traditional energy power plant, whereas with the uniform distribution of the grid's funds, executing the call option but abandoning put is the most profitable to the traditional energy power plant. Moreover, under the grid's fund of uniform distribution, it can both motivate power user consumption for clean energy generation and expand the power grid's capital size.

1. Introduction

Clean and sustainable energy power generation has greatly reduced carbon emission pollution. In recent years, wind power generation presents a large-scale development trend: the installed capacity of wind electric power has increased by about 100% in recent three years: in terms of single unit capacity, 2~3 MW wind turbines have been put into commercial operation, 5~6 MW wind turbines have completed technical development, and above10 MW wind turbines are under research and development. However, when the wind is insufficient, the electric-power plant cannot generate electricity conventionally, which will lead the electricity industry to partially out of action, hence following with huge losses to the power grid and power users downstream. Although CSE power generation helps reduce carbon emissions, intermittence restricts the large-scale use of CSE for the power generation industry. Traditional energy provides a sustainable supply, nonetheless accelerating carbon emissions and deteriorating environmental pollution [1]. The power grid adopts the dual source procurement from two types of power plants. When CSE power generation achieves sustainable supply [2], CSE power generation from the wind power plant is preferred. When CSE supply is cut off, the power grid exercises the option contract to purchase power from the traditional power plant who works as the backup supplier [3] and [4].

In addition, financial behavior between upstream and downstream enterprises in the supply chain is one of the hotspots in the research field of supply chain finance. In the electric-power supply chain, the downstream power grid executes dual purchases from two power plants, and the dual-source procurement strategy may give rise to CSE supply disruption risk. The self-owned fund's deficiency in the power grid inspires financing requirements. So, the grid's capital budget and distribution property, combined with the risk hedging strategies in different scenarios Kaufmann et al. [5], have a practical impact on the power grid's procurement decision. Further, since the two types of electric-power plants optimize decision-making on the premise of observing the follower's optimal strategy, the fund property and option hedging will also affect the plants' financing decision by the power grid procurement decision.

Based on the ESC enterprise development in China, the following research questions are proposed: Motivated by the emergence of green electricity financing, a new business model is enabled by financial derivatives options. In this paper, we aim to study the operational mechanism behind the disruption risk hedged against by options under supplier financing, explore the impact of risk hedging and financing schemes on green electricity supply chain operations, and provide management suggestions that could guide the decision-making in practice. Therefore, we focus on the following questions: (1) For the power grid, is it always motivated to hedge against risk arising from CSE intermittence by double option? (2) For the power plant *with traditional energy*, does the power plant always benefit from providing supplier financing under different options strategies? (3) For the generating plant *with* CSE, does the power plant always benefit from providing supplier financing under different option portfolios? (4) How does the introduction of the power grid's working capital property affect the three participants' operational or financial decisions in the supply chain? To answer these questions, we develop a game-theoretic model, and focus on the cases where the power grid's working capital is constant or uniformly distributed, respectively; we specifically examine participants' operational and financial strategies and the corresponding equilibrium profit in the face of the gird's financial constraint.

The main contributions of the study are as follows:

(i) Jointly considering the capital property and option hedging impacts on participants' strategies.

(ii) Introducing that the capital is uniform distribution into the ESC supply chain.

(iii) Considering double option to hedge against energy supply intermittence when the power plants provide supplier financing.

On this basis, we further investigate CSE intermittence and disruption risk with options hedging, in which case the traditional energy electricity plant acts as both the creditor and the option seller. We then examine the changes in the power grid's working capital, as well as the interest rate of each power plant. The rest of this paper is organized as follows. We first review the related literature in Section 2. In Section 3, we introduce our model and picture of the problem statement, assumption notation (sets (indices), parameters, decision variables), and all formulation solution approach. Section 4 investigates the results for the model under respective scenarios. Section 5 investigates the managerial insights and practical implications. In Section 6, we make managerial insights and practical implications. Finally, we draw conclusions and outlook in Section 7.

2. Literature Review

Our work is primarily connected with three streams of research: the literature on option hedging, the literature on supply chain finance, and the ESC operational strategy.

2.1. Option Hedging. Such literature mainly studies the retailers' optimal procurement decision, establishes models, and designs contracts under different conditions. Schummer and Vohra [4] analyzed a set of options contracts, built a model, and formulated the optimal procurement strategy, but the defect of the model is ignoring the spot market. Ritchken and Tapiero [3] established the purchase model with an option contract and considered the derivative market intersection with the spot market. This paper extends its option model to discuss the coexistence of the derivative market and spot market under supply disruption risk. Wu [6] used the method of the Nash game to analyze the optimal purchase quantity of retailers, the option premium, and the striking price of suppliers. But it assumed that supply in the spot market was infinite, which was different from this paper. For the reason of CSE intermittence, this article assumed that supply disruption was in the power spot market when using CSE for power generation. Similarly, Spinler et al. [7] and Golovachkina and Bradley [8] also analyzed this game based on the purchase model. Moreover, Martinez et al. [9]and Wu et al. [6, 10] extended the traditional purchase model to the coexistence of option and spot based on the Nash game. From the view of the power grid, this paper maximizes the expected profit of enterprises in the ESC by establishing a purchase model based on an option contract and spot market with constraint supply. Further, Fu et al. [11] studied and solved the risk management model in a purchase based on an options portfolio contract and spot market with unconstraint supply, but did not study the possible shortage in the spot market. This paper focuses on the analysis of how the power grid should optimize the purchase strategy under the options portfolio hedging contract when there is a supply disruption in the power spot market. It also analyzes factors such as the impact of power grid financial constraints, different power plants' credit loan interest rates, and power users' preference for CSE on the optimal purchase, providing guidance for power grid decision-making. Tomlin [12] studied the emergency effect of dual source procurement strategy, emergency inventory strategy, and multi-product flexible ordering strategy when suppliers have supply disruption. Cachon and Zhang. [13]studied the optimal option contract design under the condition that the supplier's production cost is used as public information, while that for the demand is as private. Li and Liu [14] specifically gave solution for the optimal dynamic trading strategy between a riskless asset and a risky asset with momentum. The dynamics models reflect the long-term projections variability and are well-suited for financial applications where long-term demographic uncertainty is relevant [15].

Most of these studies take an empirical approach to examine the option design and its impact on the supply chain, nevertheless, they merely land on disruption risk in the supply chain rather than on credit, or low-carbon requirements. In contrast, we adopt a modeling approach to explore the heterogeneous power plants' motivations to provide credit with strategic interest rates and the intentions of power gird to option design. Furthermore, given strategic interest rates and various option portfolios, our model deeply investigates the grid's reflection on the credit strategy considering the grid's funds property. And because of the assumption that the grid's fund is uniform distribution and also option hedging selection assumption, which will influence the leading factors to electricity consumption, we will proclaim the transmission mechanism of participants' decision effects on electricity consumption in ESC. And thus, our paper could be more conducive to providing suggestions for the sustainable development of ESC with supplier credit and option hedging against disruption risk.

2.2. Supplier Finance. Our study is also closely related to the literature on SCF. For example, Srinivasa Raghavan and Mishra [16] discussed the lender's decision on the number of loans to enterprises. In Gong and Chao's (2014) [17] study, retailers with capital constraints could obtain short-term financing. Kouvelis and Zhao (2016) [18] studied the coordination of the supply chain with bank loan (BL) participation. Only BL is available in the above models. In addition, trade credit (TC) is also a common financing method [19]. Chen and Wang [20], Yu , as well as Yang et al. [21]studied the impact of TC on enterprises' operational decisions. In comparison, Yang et al. [22] and Hosseini-Motlagh et al. (2018) [23] introduced competition into the retail market in which retailers solve financial distress through TC. Kouvelis and Zhao (2012) [24] focused on the optimal TC structure, but the supplier in their model allows the retailer to delay partial payment until demand is realized. Researches of Tunca and Zhu (2018) [25] and Deng et al. (2018) [26]were different from many previous studies on TC, which mainly focused on retailer capital constraints. They highlighted the role of buyer finance to address the supplier's financial needs. Kouvelis and Zhao (2018) [27]. (2019). Nguyen et al. (2019) [28] analyze the energy efficiency (EE) investment decisions with the manufacturer as the debtor who competes with an alternative supplier in order for business from a large industrial buyer and find some interesting results that assessment assistance helps reduce the EE gap but procurement commitment eliminates it.

All these papers discuss wholesale price contracts with supplier financing without considering the buyer's capital property. In contrast, we consider supplier financing under two scenarios, in one of which the buyer's working capital is constant and the other is the buyer's capital is uniformly distributed. A key feature of the buyer's working capital is that it derives different impacts on purchases. The traditionally related researches only involve the impact of the capital budget on purchasing decision but does not refer to the option hedging and the option selection influence on carbon emission reduction level, which is the leading factor in electricity consumption. Till so far, our model firstly discusses how options strategies determine the carbon emission reduction level embedded in the demand function. Even if some funds property expands the budget and inspires the electricity demand, it cannot encourage the power grid to purchase wind power radically. As a debtor, the power grid should also evaluate the disruption risk arising from wind intermittence, and then determine the optimal wind power procurement strategy under different option hedging. Compared to the existing literature ignoring the fund property and option strategy impacts on decision-making, this paper analyzes the influence of the two factors in detail, establishes decision-making models in four different scenarios, and discusses the influence of key parameters on each participant. Overall, our study provides certain guidelines for the power grid, the power plant with traditional energy, and the power plant with CSE. Crane et al. [29] Funds employ a wide range of strategies for acquiring public filings. Those that systematically scrape large volumes of information, specialize in certain filing types, acquire filings with more content changes, or access information immediately outperform other funds. C. C. Blanco [30] This study classifies 16,525 implemented carbon abatement projects using text analysis, and results show that latent classes exist and statistically differ in the sense of metrics they examine.

The research contribution is as follows:

(i) Using a Stackelberg game to evaluate optimal strategies of ESC participants.
(ii) Applying option portfolio to hedge against CSE supply disruption and discuss the impact of the options on carbon emission reduction level, which is one of the leading factors in electricity consumption.
(iii) Considering the power grid's funds may conform to a uniform distribution, combined with financing strategy and options portfolio, we investigate funds' property impact on electricity consumption under different scenarios.

2.3. Research Gap. The pieces of supply chain research literature considering SCF and options strategies are listed in Table 1, and the research aspects involved in the literature are summarized.

Table 1: Literature review.

	Option policy						SCF				
	Option contracts	Option hedge against disruption	Extended procurement model	Capital constraints	Dual source procurement	With information asymmetry	SCF strategy	BL&TC	Retailer financing	Clean energy supply intermittence	Fund property
[14, 15]	√	√	√								
[4]	√										
[3]	√	√									
[6–8]	√	√									
[6, 10]		√	√								
[11]	√	√		√							
[12]		√			√						
[13]	√					√					
[16, 17]							√				
[9, 18–22]				√			√	√			
[22, 27]									√		
[23–28]				√			√		√		
[31–34]				√			√			√	
[29, 30, 35–37]				√			√				√
This study	√	√	√	√	√		√	√		√	√

3. Problem Statement

3.1. Model Description. Take wind as the representative clean energy input to generate electricity, taking the wind power plant as the strategic supplier and the traditional energy power plant as the backup supplier, respectively. Both plants generate electric power to the power grid, who transmits electricity to its downstream users. If the power grid has financial constraints, both plants are willing to provide supplier financing.

The decision model introduces a power option contract to deal with wind supply disruption risk. For one thing, when the power grid start-up the backup supplier-that is the traditional power plant performs the consignment obligations under a low wind yield level, and the carbon emission reduction level for the whole supply chain reduces to L_2, which is lower than the carbon emission reduction level L in the previous purchase plan. So, the electric-power purchase quantity is adapted correspondingly. For another, when the wind yield rate is high, the power grid procurement strategy can be set divided into two scenarios: dual-source electric-power procurement or executing the put option to withdraw the traditional energy power order in exchange for electric-power all from the wind power plant. However, when executing the put option, the carbon emission reduction level L_1 that can be achieved by wind power generation is higher than L anticipated in the original procurement plan. Because L directly impacts demand, the power purchase quantity varies correspondingly compared with the quantity in the original procurement plan.

The decision of participants in the power supply chain can be made under four scenarios: The self-owned capital k of the power grid is constant only when executing call options; The self-owned capital k of the power grid is constant when executing both call and put; The self-owned funds of the power grid and power users are uniform distribution when the power grid only executes the call option; The self-owned funds of the power grid and the funds of power users are uniform distribution when the power grid executes both call and put. The model structure is shown in Figure 1.

3.2. Problem Assumptions

(i) Wind supply is intermittent. The actual wind yield is a certain probability distribution of $\begin{cases} 1, & \nu, \\ 0, & 1-\nu. \end{cases}$ $\nu \in (0,1)$ and is a random variable for the uncertainty of wind energy. The power output is available with probability ν and is unavailable with probability $1-\nu$. Sam and Serguei (2017) [31], Tomlin and Wang (2005) [32], Ambec and Crampes (2012) [33];

(ii) Considering the power grid funds property can be divided into two scenarios: One is that the self-owned capital is constant for k, and the other is that the capital is uniformly distributed on $U \sim (0, (1/\alpha))$.

(iii) The electricity demand function adopts a linear form $q = A - \alpha p + \beta L$. When the wind yield rate is low, the carbon emission reduction level is L_2. When the wind yield rate is high, the level turns to be L_1, and $L_1 > L > L_2$.

In this section, we have described the problem indices. We will examine the problem decision variables, parameters, and problem primitives, all of which are shown in Tables 2–5:

We will provide the mathematical model of the research as follows:

The wind power plant decides the commercial credit interest rate r_w. As the leader of the Stackelberg game, he can observe the optimal wind power ordering decision Q_w^* and the optimal credit strategy r_G^*. Here, both commercial credit rate r_w and r_G are the dependent variable of Q_w. Considering such influential factors as the probability of wind, and wind intermittent, the power grid adopts different options and strategies to hedge the supply disruption risk.

(i) The power grid's purchasing strategy

The power grid executes the call option under dual purchase.

(ii) When wind is insufficient

The power grid purchases electricity from two heterogeneous energy power plants. The power grid plans to purchase electricity Q_w from the wind power plant. The total power purchase quantity can be written as the multiple forms of Q_w, which is δQ_w. Then it is planned to purchase electricity from traditional power plants $Q_{G2} = (\delta - 1)Q_w$.

If the wind power supply is cut off due to the wind being insufficient, that is $Q_w = 0$, the power grid must execute the call option. The power grid purchases power from the traditional energy power plant. In this case, the working capital of the power grid is expressed as its own capital with a constant k, not related to the funds of the downstream users. If the power grid purchases a double option, the sum of total expenditure for the power grid includes the total electric-power purchase cost and option premium. Considering that the self-owned funds of the power grid are not enough to pay for all the purchases, financial behavior is required in the power purchase process. The financing limit is provided by the upstream power plant (the creditor) is B_{G2}. The power grid (the debtor) as the follower in the Stackelberg game cannot observe the decisions of the leader and subleader by the reverse induction method, and the financing interest rate r_G is regarded as a given constant. Then the profit function of the power grid is

$$\pi_{R1}(Q_{G2}) = -k + pq - (1 + r_G) \cdot B_{G2}. \quad (1)$$

Call option executing under low wind yield will increase the procurement from traditional energy power generation. This causes more traditional energy consumption with high levels of carbon emission. Therefore, the carbon emission reduction level reduces from L to L_2. The carbon emission reduction level will affect the power market demand. The

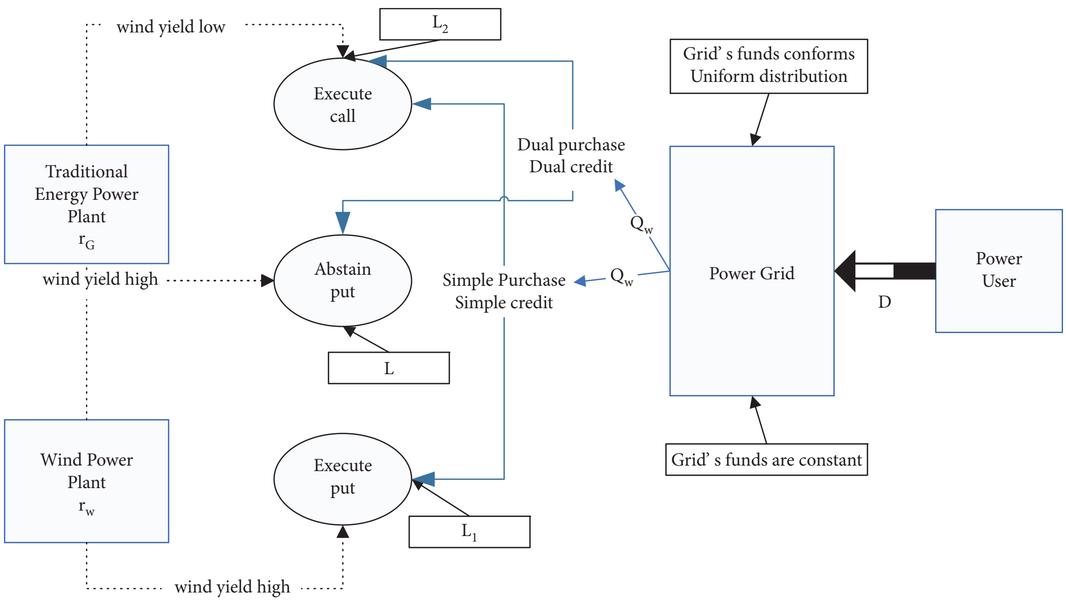

Figure 1: Supply chain participants' decisions under different option hedging with varied funds property of the grid.

Table 2: Subscripts and superscripts.

Subscripts and superscripts	Description
w, G, R	The renewable type of plant, the traditional type of plant, the gird
w, g	Direct financing from renewable tydslupe plants, direct financing from a traditional type plant

Table 3: Decision variables.

Decision variables	Description
r_w	Supplier financing interest from the renewable energy type of plant
r_G	Supplier financing interest from the traditional energy type of plant
Q_w	Induced order quantity under the renewable type generation

total amount of power procurement decreases to $Q_{G2} + Q_w - \beta(L - L_2)$. Therefore, the power grid profit function is

$$\pi_R(Q_w) = p[q - \beta(L - L_2)] - k - (1 + r_G) \cdot B_{G2}. \tag{2}$$

The power grid credit line is $B_{G2} = w_2[q - \beta(L - L_2)] + w_7(R_1 + R_2) - k$, $B_{G2} > 0$ is the constraint condition. Among them, $q = Q_w + Q_{G2} = \delta Q_w, \delta > 1$. Therefore, when the power grid finds Q_w through the optimization process, the total purchase amount δQ_w can be obtained accordingly. Then q is obtained.

(i) When wind is sufficient

The power grid abstains from the put option and sticks to the dual source purchasing, which leads to an additional loss of the option premium. Otherwise, the power grid plans to purchase power Q_w from the wind power plant, and $\dot{Q}_{G1}$ from traditional power plants. On-grid price of new energy power plants is represented by wind power generation w_1. In this case, the self-owned capital of the power grid is a constant presented by k. Since p and L in the demand are exogenous variables, given p and L, the power market demand can be determined following this equation: $q = A - \alpha p + \beta L = \vartheta Q_w$, and the retail price of electricity is $p = (A - q + \beta L/\alpha)$. Therefore, the electricity purchased from traditional energy power plants time is $\dot{Q}_{G1} = (\vartheta - 1)Q_w, \vartheta > 1$. Since the power grid has not adjusted the proportion of wind power, the carbon emission reduction level is still L, and the market electricity demand remains unchanged in this scenario.

Here, considering that the self-owned funds of the power grid are insufficient, the power grid can borrow from the two types of power plants respectively. The two power plants will formulate their financing interest rate strategies which amount to the power grid's financing cost. The credit line from the traditional energy power plant is $\dot{B}_{G1} = w_2\dot{Q}_{G1} - k_G = w_2(\vartheta - 1)Q_w + w_7(R_1 + R_2) - k_G$. The power grid will pay for part of the purchase funds k_G to power plants in advance, $k_G = gk$, whereas the balance payment will delay to pay. In addition, the credit line from wind power plants is $\dot{B}_w = w_1 Q_w - k_w$. It pays part of the purchase funds k_w to the wind power plant in advance, and $k_w = (1 - g)k$. We use inequality $\dot{B}_{G1} + \dot{B}_w > 0$ to show the power grid's financial constraints. Therefore, when the power grid finds the

Table 4: Problem primitives.

Problem primitives	Description
w_1	The wholesale price offered by the renewable energy type of electricity plant, which also is the strike price of the put option
w_2	The wholesale price offered by the traditional energy type of electricity plant, which also is the strike price of a call option
w_7	The option premium
p	Electricity retail price
δ	The coefficient of total order quantity with respect to wind power generation whose capital is constant when the wind is unavailable and the call option is exercised
ϑ	The coefficient of total order quantity with respect to wind power generation whose capital is constant when the wind is available and only the call option is exercised
τ	The coefficient of total order quantity with respect to wind power generation whose capital is constant when the wind is available and call and put options are both exercised
δ_1	The coefficient of total order quantity with respect to wind power generation whose capital is uniform when the wind is unavailable and the call option is exercised
ϑ_1	The coefficient of total order quantity with respect to wind power generation whose capital is uniform when the wind is available and only the call option is exercised
τ_1	The coefficient of total order quantity with respect to wind power generation whose capital is uniform when the wind is available and call and put options are both exercised
w_7	Option premium
$\alpha\beta A$	Price elasticity of electric user demand/who's reciprocal cap on electricity users' funds carbon emission reduction level elasticity of electricity user demand electricity users spontaneous demand
c_1	Climbing and start-up costs
c_2	Power generation operation and energy procurement costs
c_3	Service cost for normal operation and maintenance of wind turbines
L	The carbon emissions reduction level
L_1	The carbon emissions reduction level when exercising the put option and replenishment wind energy electricity
L_2	The carbon emissions reduction level when exercising the call option and replenishment of traditional energy electricity
k	The grid's working capital
g	The payment proportion for the traditional type of plant when the grid makes electricity procurement ordering
k_G	A part of the grid's working capital paid for the procurement from the traditional type of plant
k_w	A part of the grid's working capital paid for the procurement of renewable types of plant
R_1	The call option's quantities
R_2	The put option's quantities
D	Demand
w_1	The wholesale price offered by the renewable energy type of electricity plant, which also is the strike price of the put option
w_2	The wholesale price offered by the traditional energy type of electricity plant, which also is the strike price of a call option

Table 5: Variables introduced during analysis.

Variables introduced during analysis	Description
q	The total order quantity before the actual wind availability is observed
B_w	Direct financing amount from the wind generation plant
B_G	Direct financing amount from the traditional generation plant
Q_G	Induced order quantity under traditional type generation

optimal solution for Q_w, the total purchase amount ϑQ_w can be obtained accordingly. Then $\dot{Q}_{G1}$ is further obtained from $\dot{B}_{G1}$. Therefore, the power grid profit function is

$$\pi_{R1}\left(Q_w, \dot{Q}_{G1}\right) = -k + pq - \left(1 + r_G\right) \cdot \dot{B}_{G1} - \left(1 + r_w\right) \cdot \dot{B}_w. \tag{3}$$

(i) Under the dual source power procurement where the power grid only executes the call option, the profit for the power grid is

$$\pi_{R-1} = (1 - \nu)\pi_R\left(Q_{G2}, Q_w\right) + \nu\pi_R\left(\ddot{Q}_{G1}, Q_w\right), \tag{4}$$

$$\text{s.t. } B_{G2} \geq 0, \tag{4a}$$

$$\text{s.t. } \dot{B}_w \geq 0, \tag{4b}$$

$$\text{s.t. } \dot{B}_{G1} \geq 0, \tag{4c}$$

$$\text{s.t. } \pi_w\left(r_w\right) > 0. \tag{4d}$$

The power grid performs the option seller's obligations under the double option exerted.

(ii) When the wind power is insufficient

The power grid profit function is

$$\pi_R(Q_w) = p[q - \beta(L - L_2)] - k - (1 + r_G) \cdot B_{G2}. \quad (5)$$

Here, wind energy is abundant and the wind power generation exceeds the order quantity. In this situation, the power grid chooses to execute the put option, withdrawing the preceding order and changing to repurchasing more wind electric power. This can not only make better use of abundant CSE but also improve the carbon emission reduction level, which can better meet the power market demand for a strong preference for CSE generation.

In this case, the demand $q = A - \alpha p + \beta L = \tau Q_w$. Therefore, the retail price of electricity can be rewritten as $p = (A - q + \beta L/\alpha)$. The self-owned funds of the power grid are not enough to pay all the orders, so the grid as debtor applies for the credit line from the upstream traditional energy power plant, which is $\ddot{B}_{G1}$. Since additional wind power plant orders will substitute for the traditional energy order, it will promote the carbon emission reduction level to L_1. Then the total power procurement increases by $\beta(L_1 - L)$. Because exercising the put option causes us to buy back the preceding traditional energy power, then we have $\ddot{Q}_{G1} = 0$, and $\ddot{B}_{G1} = 0$. Here, the profit function of the power grid is

$$\pi_{R1}\left(Q_w, \ddot{Q}_{G1}\right) = -k + p[\tau Q_w + \beta(L_1 - L)] - (1 + r_w) \cdot \ddot{B}_w. \quad (6)$$

When executing a double option portfolio, the weighted average profit of the power grid is

$$\pi_{R-1} = (1 - \nu)\pi_R(Q_{G2}, Q_w) + \nu\pi_R\left(\ddot{Q}_{G1}, Q_w\right), \quad (7)$$

$$\text{s.t. } B_{G2} > 0, \quad (7a)$$

$$\text{s.t. } \ddot{B}_w \geq 0. \quad (7b)$$

(i) The traditional energy power plant's financing strategy

Traditional energy power plants need to pay equipment operation and maintenance costs and power generation energy procurement costs. Considering different option contract execution strategies from the power grid, the profit function of traditional energy power plants should also be weighted average in the light of wind yield rate.

The power plant performs the call option seller's obligations under dual purchase.

When the wind is insufficient, the profit function of the traditional energy power plant is as follows:

$$\pi_{G-C}(r_G) = k_G + (1 + r_G) \cdot B_{G2} - (c_1 + c_2)Q_{G2}. \quad (8)$$

Among them, the prepaid part $k_G = gk$ and the credit line here is $B_{G2} = w_2[q - \beta(L - L_2)] + w_7(R_1 + R_2) - k$.

(i) When the wind is sufficient

When the power grid abandons the put option while the wind yield rate is high, the profit function of the traditional energy power plant is as follows

$$\pi_{G-N}(r_G) = k_G + (1 + r_G) \cdot \dot{B}_{G1} - (c_2 + c_1) \cdot \dot{Q}_{G1}. \quad (9)$$

From them, we have. $\dot{Q}_{G1} = (\vartheta - 1)Q_w$

The weighted average profit of the traditional energy power plant is

$$\pi_{G-1} = (1 - \nu)\pi_{G-C}(Q_{G2}, Q_w) + \nu\pi_{G-N}\left(\dot{Q}_{G1}, Q_w\right), \quad (10)$$

$$\text{s.t.} B_{G2} > 0, \quad (10a)$$

$$\text{s.t.} \dot{B}_{G1} > 0. \quad (10b)$$

The power plant performs as the call option seller under the double option exerted.

(i) When the wind is insufficient

n this part, the traditional energy power plant profit function is the same as the function (8).

(ii) When the wind is sufficient.

Here, when the power grid executes the put option, the power plant repurchases all power orders. The traditional energy power plant shall stock energy to fulfill the original power order $\ddot{Q}_{G1} = (\tau - 1)Q_w$, but there still has c_2 cost even if the grid buys backorders. However, there are no start-up and climbing costs. Therefore, the profit of the energy power plant is the sum of the income of the option fee minus some costs and fees such as the expenditure of raw materials, operational costs, and maintenance costs. The profit function is

$$\begin{aligned}\pi_{\text{put}}(r_G) &= w_7(R_1 + R_2) - c_2\ddot{Q}_{G1} \\ &= w_7(R_1 + R_2) - c_2(\tau - 1)Q_w.\end{aligned} \quad (11)$$

The weighted average profit of the power plant is $\pi_{G-2} = (1 - \nu)(\pi_{\text{cal}}) + \nu(\pi_{\text{put}})$.

(iii) The wind power plant's financing strategy

The setting of r_w will also be affected by the option strategy. According to the decision-making process of the Stackelberg game, the decision sequence of each participant is as follows: wind power plant takes the lead in determining commercial credit interest rate r_w through observation r_G^* and Q_w^*, then given r_w the traditional energy power plant determines credit interest rate r_G by observing the power grid procurement strategy Q_w^*. Finally, the credit interest rate strategy r_w and r_G, the power grid determines the wind power procurement strategy Q_w.

(iv) Only call option transaction is exerted under dual purchase

(v) When the wind is insufficient

With low wind yield, the wind power supply is disrupted, $Q_w = 0$, and the wind power plant has no yield or profit.

(vi) When the wind is sufficient

The wind power plant generates electric power according to the previous procurement plan. The plant profit is

$$\pi_w(r_w) = k_w + (1 + r_w)\dot{B}_w - c_3 Q_w, \tag{12}$$

$$\text{s.t. } \pi_w(r_w) > 0, \tag{12a}$$

$$\text{s.t. } \dot{B}_w > 0. \tag{12b}$$

Here, $\dot{B}_w = w_1 \cdot Q_w - k_w$, $k_w = (1 - g)k$.

(vii) When the power supply chain enterprise executes the put option transaction, the profit of the wind power plant is

$$\pi_{w-1}(r_w) = v(k_w + (1 + r_w) \cdot (w_1 \cdot Q_w - k_w) - c_3 Q_w). \tag{13}$$

The wind power plant performs as put option transaction seller under double option exerted

(viii) When the wind is insufficient

With low wind yield, the wind power supply is disrupted. The wind power plant has no yield or profit.

(ix) When the wind is sufficient

The wind power plant generates electric power according to the original procurement plan. Due to the wind energy particularity, the acquisition cost of wind energy is almost zero. However, wind power generation will produce the service cost of maintaining the normal operation and maintenance of wind turbines c_3. The wind power plant profit is

$$\pi_w(r_w) = k_w + (1 + r_w)\dot{B}_w - c_3 Q_w, \tag{14}$$

$$\text{s.t. } \pi_w(r_w) \rangle 0, \tag{14a}$$

$$\text{s.t.} \dot{B}_w > 0, \tag{14b}$$

here, $\dot{B}_w = w_1 \cdot Q_w - k_w$, $k_w = (1 - g)k$.

When the power supply chain participant executes the put option transaction, the weighted average profit of the wind power plant is

$$\pi_{w-1}(r_w) = v(k_w + (1 + r_w) \cdot (w_1 \cdot Q_w - k_w) - c_3 Q_w). \tag{15}$$

It can provide more electricity than the original order. The traditional energy power plant sells the put option and purchases additional power from the wind power plant when the put option is executed. The wind power plant undertakes all power generation, and the number of wind power orders is updated to $\tau Q_w + \beta(L_1 - L)$, and $\ddot{B}_w = w_1 \cdot (\tau Q_w + \beta(L_1 - L)) - k$.

$$\pi_w(r_w) = k + (1 + r_w)\ddot{B}_w - c_3[Q_w + \beta(L_1 - L)], \tag{16}$$

$$\text{s.t.} \ddot{B}_w > 0. \tag{16a}$$

When executing the put option, the weighted average profit of the power grid is

$$\pi_{w-2} = v(k + (1 + r_w)B_w - c_3(\tau Q_w + \beta(L_1 - L))). \tag{17}$$

(i) The Power Grid's Purchasing Strategy

the power user is downstream against the power grid. It is assumed that the user's funds y is of the uniform distribution.

$f(y) = \begin{cases} (1/(1/\alpha)) = \alpha, & 0 < y < (1/\alpha), \\ 0, & \text{else}, \end{cases}$

$F(y) = \begin{cases} \alpha y, & 0 \le y \le (1/\alpha), \\ 1, & y > (1/\alpha). \end{cases}$ The power grid funds come from the power users with regular payments for electricity bills. It is assumed that the number of users with power demand in the market is standardized as 1(Tian et al., 2018 [34]; Abhishek, 2016 [35]; Gao et al., 2015 [36]; Xie et al., 2021 [37]). Then the self-owned funds x for the power grid are related to the funds of its downstream users and also conform to a uniform distribution, $f(x) = \begin{cases} \alpha, & 0 < x < (1/\alpha), \\ 0, & \text{else}, \end{cases}$ $F(x) = \begin{cases} \alpha x, & 0 \le x \le (1/\alpha), \\ 1, & x > (1/\alpha). \end{cases}$

Therefore, the self-owned funds of the power grid are $\int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x = (1/2\alpha)$, Market demand is affected by electricity price p, carbon emission reduction level L and consumer capital level y.

(ii) Only Executes the Call Option

(iii) When the wind is insufficient

The capital of the power grid is related to the capital of downstream power users. So, the profit of the power grid is

$$\pi_R(Q_w) = p[q - \beta(L - L_2)] - k - (1 + r_G) \cdot \overline{B}_{G2}, \tag{18}$$

$$\text{s.t. } \overline{B}_{G2} > 0, \tag{18a}$$

where $\overline{B}_{G2} = w_2[q - \beta(L - L_2)] + w_7(R_1 + R_2) - (1/2\alpha)$, $\delta_1 Q_w = Q_w + \overline{Q}_{G2}$, $(\delta_1 > 1)$. So, $\overline{Q}_{G2} = (\delta_1 - 1)Q_w$.

(iv) When the wind is sufficient

$$\pi_{R1}(Q_w, \overline{Q}_{G1}) = -k + pq - (1 + r_G) \cdot \overline{B}_{G1} - (1 + r_w) \cdot \overline{B}_w, \tag{19}$$

$$\text{s.t. } \overline{B}_{G1} > 0, \tag{19a}$$

$$\text{s.t. } \overline{B}_w > 0, \tag{19b}$$

where $\overline{B}_{G1} = w_2\overline{Q}_{G1} - k_G = w_2(\vartheta_1 - 1)Q_w + w_7(R_1 + R_2) - k_G$, $k_G = g\int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x, g < 1$, credit line supplied by the wind power plant is $\overline{B}_w = w_1 \cdot Q_w - k_w$, where $k_w = (1 - g)\int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x$ and $\overline{Q}_{G1} = (\vartheta_1 - 1)Q_w$. The total amount of procurement plan formulated by the power grid is $q = A - \alpha p + \beta L = \vartheta_1 Q_w, \vartheta_1 > 1$. The weighted average profit of the power grid is

$$\pi_{R-U1} = (1 - \nu)\pi_R(\overline{Q}_{G2}, Q_w) + \nu\pi_R(\overline{Q}_{G1}, Q_w), \tag{20}$$

$$s.t. \overline{B}_{G2} > 0, \tag{20a}$$

$$s.t. \overline{B}_w > 0, \tag{20b}$$

$$s.t. \overline{B}_{G1} > 0. \tag{20c}$$

(v) The Power Grid Executes Double Option

When the wind power is insufficient, the power grid profit is the same as that in equation (18).

When wind energy is abundant

If the power generation exceeds the order quantity. The power grid purchases and exercises put options from the traditional power plant. All funds can be used to purchase CSE power, to remission carbon emissions under the current budget. The total procurement quantities are still set in multiple forms of Q_w. $\tau_1 Q_w = Q_w + \overline{\overline{Q}}_{G2}, \tau_1 > 1$, then the power grid's profit is

$$\pi_{R1}\left(Q_w, \overline{\overline{Q}}_{G1}\right) = -k + p\left(\overline{\overline{Q}}_{G1} + Q_w\right) - (1 + r_w) \cdot \overline{\overline{B}}_w, \tag{21}$$

$$\text{s.t. } \overline{\overline{B}}_w > 0, \tag{21a}$$

where $\overline{\overline{B}}_w = w_1 \cdot [Q_w + \overline{\overline{Q}}_{G1} + \beta(L_1 - L)] - k = w_1(\tau_1 Q_w + \beta(L_1 - L)) - (1/2\alpha)$

The weighted average profit of the grid is

$$\pi_{R-U2} = (1 - \nu)\pi_R\left(\overline{\overline{Q}}_{G2}, Q_w\right) + \nu\pi_R\left(\overline{\overline{Q}}_{G1}, Q_w\right), \tag{22}$$

$$\text{s.t. } \overline{B}_{G2} > 0, \tag{23}$$

$$\text{s.t. } \overline{\overline{B}}_w > 0. \tag{24}$$

(i) The Traditional Energy Power Plant's Financing Strategy

The power plant performs the seller's obligations under dual purchase.

When the wind power is insufficient, the profit function for the traditional energy power plant is

$$\pi_{G-UC}(r_G) = x + (1 + r_G) \cdot \overline{B}_{G2} - (c_1 + c_2)\overline{Q}_{G2}, \tag{25}$$

$$\text{s.t. } \overline{B}_{G2} > 0, \tag{25a}$$

where the credit line is $\overline{B}_{G2} = w_2(\delta_1 Q_w - \beta(L - L_2)) + w_7(R_1 + R_2) - (1/2\alpha)$, the total electric power is $\delta_1 Q_w = Q_w + \overline{Q}_{G2}$, $\overline{Q}_{G2} = (\delta_1 - 1)Q_w$.

When wind energy is abundant, the profit function for the traditional energy power plant is

$$\pi_{G-UN}(r_G) = k_G + (1 + r_G) \cdot \overline{B}_{G1} - (c_2 + c_1) \cdot \overline{Q}_{G1}, \tag{26}$$

$$\text{s.t. } \overline{B}_{G1} > 0, \tag{26a}$$

where the credit line is $\overline{B}_{G1} = w_2(\vartheta_1 - 1)Q_w + w_7(R_1 + R_2) - k_G$, the part of the payment in advance is $k_G = g\int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x, g < 1$, $\overline{Q}_{G1} = (\vartheta_1 - 1)Q_w$.

The weighted average profit of the traditional energy power plant is

$$\pi_{G-U1} = \int_0^{(1/\alpha)} ((1 - \nu)\pi_{G-UC} \cdot + \nu(\pi_{G-UN}))\alpha\mathrm{d}x, \tag{27}$$

$$\text{s.t. } \overline{B}_{G2} > 0. \tag{27a}$$

When the power grid executes the put option, the traditional energy power plant performs the obligations of the call option seller

(ii) The wind is insufficient

In this part, the traditional energy power plant profit function is the same as the function (20)

(iii) The wind is sufficient

$$\pi_{G-\mathrm{UCP}}(r_G) = x + (1+r_G)\cdot \overline{B}_{G2} - (c_1+c_2)\overline{Q}_{G2}, \tag{28}$$

$$\text{s.t. } \overline{B}_{G2} > 0. \tag{28a}$$

Here, when the power grid executes the put option, the power plant buybacks all power orders. The traditional energy power plant shall prepare power generation energy to fulfill the original power order $\overline{\overline{Q}}_{G1} = (\tau_1 - 1)Q_w$. The profit function is

$$\pi_G(r_G) = w_7(R_1+R_2) - c_2(\tau_1-1)Q_w, \tag{29}$$

$$\text{s.t. } \pi_G(r_G) > 0. \tag{29a}$$

According to the above analysis, the weighted average profit of the power plant is

$$\pi_{G-U2} = \int_0^{(1/\alpha)} ((1-v)(\pi_{G-\mathrm{UCP}}) \cdot + v(\pi_{G-\mathrm{UP}}))\alpha \mathrm{d}x, \tag{30}$$

$$\text{s.t. } \overline{B}_{G2} > 0. \tag{30a}$$

3.2.1. The Wind Power Plant's Financing Strategy. When the power grid abandons the put option, the wind power plant will supply power according to the original plan.

(i) When the wind is insufficient

With low wind yield, the wind power supply is disrupted. The wind power plant has no yield and no profit.

(ii) When the wind is sufficient

The profit of the power plant is

$$\max \pi_w(r_w) = \int_0^{(1/\alpha)} \{k_w + (1+r_w)\overline{B}_w - c_3 Q_w\}\alpha \mathrm{d}x, \tag{31}$$

$$\text{s.t. } \overline{B}_w > 0, \tag{31a}$$

where $\overline{B}_w = w_1 \cdot Q_w - k_w$, and $k_w = (1-g)\int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x$.

When the power grid abandons the put option transaction, the weighted average profit of the wind power plant is

$$\pi_{w-U1} = v\left\{\int_0^{(1/\alpha)} [(1-g)x + (1+r_w) \cdot (w_1\cdot Q_w - (1-g)x) - c_3 Q_w]\alpha \mathrm{d}x\right\}. \tag{32}$$

3.2.2. The Power Grid Executes the Put Option So That the Wind Power Plant Provides Additional Power beyond the Primitive Plan

(i) When the wind is insufficient

With low wind yield, the wind power supply is disrupted. The wind power plant has no yield and no profit.

When the wind is sufficient, the profit of the power plant is

$$\pi_w(r_w) = \int_0^{(1/\alpha)} \{x + (1+r_w) \cdot (w_1\cdot[\tau_1 Q_w + \beta(L_1 - L)] - x) - c_3(\tau_1 Q_w + \beta(L_1 - L))\}\alpha \mathrm{d}x, \tag{33}$$

$$\text{s.t. } \overline{B}_w > 0, \tag{33a}$$

where $\overline{B}_w = w_1 \cdot [\tau_1 Q_w + \beta(L_1 - L)] - \int_0^{(1/\alpha)} x(\alpha)\mathrm{d}x$.

3.3. Solution Method. According to the risk-aversion methods of different option portfolios adopted by the power grid, the optimal wind power procurement strategy can be solved in two situations: one is a single options strategy: executing call option to buy the wind electric power when the wind yield is low whereas abstaining the call option when the wind yield is high; the other is the dual option procurement strategy: executing call option when the wind yield is high and switching on a put option when the wind yield is high. The power grid establishes the weighted average profit function by different wind yield rates and then finds the optimal solution Q_w^* in each situation by optimization processing.

4. Results

Proposition 1. *There is an optimal purchasing strategy Q_w^* which can maximize the power grid's profit without considering the constraints. We have Q_{w1} when $B_{G2} = 0$ and we have Q_{w2} when $\dot{B}_w = 0$, then we have Q_{w3} when $\dot{B}_{G1} = 0$. Then we have the following conclusions:*

(i) *When $Q_w^* > Q_{w1}$, given all the other parameters, the optimal wind power purchase strategy of the power grid with financing is Q_w^*, that is $Q_w = Q_w^*$.*

(ii) *When $Q_w^* < Q_{w1}$, the grid purchases the electricity of quantity Q_{w1}, that is $Q_w = Q_{w1}$. However, at this time, the two types of power plants cannot relate their own decision to the optimal strategy of the power grid, so they cannot make decisions with Q_{w1}.*

(iii) *When $\dot{B}_w \geq \dot{B}_{G1} \geq B_{G2}$, then $Q_w^* = Q_{w2} = (gk - w_7(R_1+R_2)/w_2(\vartheta - 1))$. However, the two types of power plants cannot make decisions with Q_{w2};*

(iv) *When $\dot{B}_w \geq B_{G2} \geq 0$, then $Q_w^* = Q_{w3} = ((1-g)k/w_1)$. However, the two types of power plants cannot make decisions related to Q_{w3}.*

Proposition 2. *There is the optimal purchasing strategy Q_w^*, which can maximize the power grid's profit without financial constraints. We have Q_{w1} when $B_{G2} = 0$ and we have Q_{w2} when $\ddot{B}_w = 0$. Whereas considering the constraints*

$B_{G2} \geq \ddot{B}_w \geq 0$, when wind yield is low the grid executes the call option to hedge against wind electric-power disruption, and when wind yield is high the grid executes the put option. If the parameters δ and τ satisfy inequality conditions $(k - w_7(R_1 + R_2) + w_2\beta(L - L_2)/w_2\delta) > (k/\tau w_1) - (\beta/\tau)(L_1 - L)$, then we have the following conclusions:

(i) *When $Q_w^* > Q_{w1}$, given all the other parameters, the optimal wind power purchase strategy of the power grid with financing is Q_w^*, that is $Q_w = Q_w^*$;*

(ii) *When $Q_w^* < Q_{w1}$, the grid purchases the electricity with quantity Q_{w1}, that is $Q_w = Q_{w1}$. However, at this time, the two types of power plants cannot associate their decision to the optimal strategy of the power grid, so they cannot make decisions as reflection functions of Q_{w1}.*

Considering the constraints $\ddot{B}_w \geq B_{G2} \geq 0$, and δ and τ satisfy inequality condition: $(k/\tau w_1) - (\beta/\tau)(L_1 - L) > (k - w_7(R_1 + R_2) + w_2\beta(L - L_2)/w_2\delta)$, then we have conclusions.

(iii) *When $Q_w^* > Q_{w2}$, given all the other parameters, the optimal wind power purchase strategy of the power grid with financing is Q_w^*, that is $Q_w = Q_w^*$;*

(iv) *When $Q_w^* < Q_{w2}$, the grid purchases the electricity with quantity Q_{w2}, that is $Q_w = Q_{w2}$. However, at this time, the two types of power plants cannot make decisions associated with the optimal strategy of the power grid.*

Corollary 1. *Given other parameters, Q_w is a decreasing function of α, and is an increasing function of β.*

Proposition 3. *Without considering financial constraints, the optimal credit strategy of the traditional energy power plant is r_G^*. Nonetheless, considering financing constraints and with low wind yield, the grid executes the call option; with high wind yield, the grid abstains from executing the put option. If the parameters δ and ϑ satisfy the inequality conditions: $w_2(\vartheta - 1)Q_w^* - gk \geq w_2[\delta Q_w^* - \beta(L - L_2)] - k$, we will have conclusions.*

(1) *if $B_{G2} \geq \dot{B}_{G1} \geq 0$, by financial constraints $B_{G2} \geq 0$ and when the constraint is tight, the corresponding interest rate r_{G2} can be obtained, but if $r_G^* \leq r_{G2}$, the optimal interest rate is r_G^*;*

(2) *if $\dot{B}_{G1} \geq B_{G2} \geq 0$, by financial constraints $\dot{B}_{G1} \geq 0$ and, when the constraint is tight, the corresponding interest rate r_{G1} can be obtained, but if $r_G^* \leq r_{G1}$, the optimal interest rate is r_G^*.*

Corollary 2. *Given other parameters, there is a threshold for $L_2 = L_{20}$, when $L_2 > L_{20}$, r_G is a decreasing function of β, when $L_2 < L_{20}$, r_G is an increasing function of β.*

Proposition 4. *Without considering financial constraints, the optimal corresponding interest rate is r_G^*; Considering financing constraints $B_{G2} \geq \dot{B}_{G1} \geq 0$, and by $B_{G2} \geq 0$, the corresponding interest rate r_{G2} can be obtained under tight constraints. Then if $r_G^* \leq r_{G2}$, the optima interest rate is r_G^*.*

Corollary 3. *Given other parameters, there is a threshold for $v = v_{00}$, when $v < v_{00}$, r_G is a decreasing function of β; when $v > v_{00}$, r_G is an increasing function of β.*

Proposition 5. *The optimal financial strategy without considering financial constraints is r_w^*. When considering financing constraints, by financial constraints $\dot{B}_w \geq 0$ and when this constraint is tight, r_{w1} can be obtained and the optimal interest rate is r_w^*, and $r_w^* \leq r_{w1}$.*

Corollary 4. *Given other parameters, there is a threshold for $L_2 = L_{22}$, when $L_2 > L_{22}$, r_w is a decreasing function of β; when $L_2 < L_{22}$, r_w is an increasing function of β.*

Proposition 6. *Without considering financial constraints, the optimal financial strategy is r_w^*. When considering financing constraints, by financial constraints $\ddot{B}_w \geq 0$ and when the constraint is tight, r_{w2} can be obtained and the optimal interest rate is r_w^* when $r_w^* \leq r_{w2}$.*

Corollary 5. *Given other parameters, there is a threshold for $v = v_{01}$, when $v < v_{01}$, r_w is a decreasing function of β; when $v > v_{01}$, r_w is an increasing function of β.*

Proposition 7. *There is an optimal purchasing strategy Q_w^* who can maximize the power grid's profit without considering the constraints. We have Q_{w1} when $\overline{B}_{G2} = 0$ and we have Q_{w2} when $\overline{B}_w = 0$, then we have Q_{w3} when $\overline{B}_{G1} = 0$.*

(i) *considering the constraints, when $\overline{B}_{G2} > max(\overline{B}_w, \overline{B}_{G1})$, $Q_w^* > Q_{w1}$. If $Q_w^* > Q_{w1}$, $Q_w = Q_w^*$; while if $Q_w^* < Q_{w1}$, $Q_w = Q_{w1}$;*

(ii) *considering the constraints $\overline{B}_w \geq \overline{B}_{G1} \geq \overline{B}_{G2}$, $Q_w^* = Q_{w2}$. However, the two types of power plants cannot make decisions associated with the grid's strategy;*

(iii) *when $\overline{B}_w \geq \overline{B}_{G2} \geq 0$, then $Q_w^* = Q_{w3}$. However, the two types of power plants cannot make decisions associated with the grid's strategy;*

Corollary 6. *Given other parameters, there is a critical value for $g = g_0$, when $g > g_0$, Q_w is convex with α and $Q_w(\alpha_{00})$ is the minimal value; when $g < g_0$, Q_w is concave with α and $Q_w(\alpha_{00})$ is the maximal value. Q_w is an increasing function of β.*

Proposition 8. *There is an optimal purchasing strategy Q_w^* without considering the constraints. We have Q_{w1} when $\overline{B}_{G2} = 0$ and we have Q_{w2} when $\overline{B}_w = 0$.*

(i) *considering the constraints, when $\overline{B}_{G2} \geq \overline{\overline{B}}_w \geq 0$. If $Q_w^* > Q_{w1}$, $Q_w = Q_w^*$; while if $Q_w^* < Q_{w1}$, $Q_w = Q_{w1}$;*

(ii) *considering the constraints $\overline{\overline{B}}_w \geq \overline{B}_{G2} \geq 0$, $Q_w^* = Q_{w2}$. However, the two types of power plants cannot make decisions in this condition;*

Corollary 7. *Given other parameters, Q_w is convex with α and α_{01} is the minimal value; Q_w is an increasing function of β.*

Proposition 10. *Without financial constraints, the optimal financial strategy is r_G^*. When considering financial constraints, if the financial constraint $\overline{B}_{G2} \geq 0$ is tight, we have r_{G2}. The optimal interest rate solution is r_G^* and satisfy $r_G^* \leq r_{G2}$.*

Corollary 9. *Given other parameters, there is a threshold $\alpha = \alpha_{030}$ for $(d^2 r_G/d\alpha^2) = 0$, and there is another threshold $\alpha = \alpha_{03}$ for $(dr_G/d\alpha) = 0$,*

(i) If $\alpha_{03} > \alpha_{030}$, then we have,

when $\alpha > \alpha_{030}$, r_G is convex with α, when α is assigned with interior solution, r_G reach the minimal value $r_G(\alpha_{03})$,

when $\alpha < \alpha_{030}$, r_G is concave with α, when α is assigned with corner solution, r_G reach the maximum value $r_G(\alpha_{030})$;

(ii) If $\alpha_{03} < \alpha_{030}$, then we have,

when $\alpha > \alpha_{030}$, r_G is convex with α, when α is assigned with corner solution, r_G reach the minimal value $r_G(\alpha_{030})$,

when $\alpha < \alpha_{030}$, r_G is concave with α, when α is assigned with interior solution, r_G reach the maximum value $r_G(\alpha_{03})$;

(iii) There is a threshold for $v = v_{01}$, when $v > v_{01}$, r_G is a decreasing function of β; when $v < v_{01}$, r_G is an increasing function of β.

Proposition 11. *Without financial constraints, the optimal financial strategy is r_w^*. When considering financing constraints, by financial constraints $\overline{B}_w = w_1 \cdot Q_w - (k/2\alpha) \geq 0 \dot{B}_w \geq 0$ and when the constraint is tight, the corresponding interest rate is r_{w2} and the optimal interest rate is r_w^*, and $r_w^* \leq r_{w2}$.*

Corollary 10. *Given other parameters, there is a threshold $\alpha = \alpha_{040}$ for $(d^2 r_w/d\alpha^2) = 0$, and there is another threshold $\alpha = \alpha_{04}$ for $(dr_w/d\alpha) = 0$,*

(i) If $\alpha_{04} > \alpha_{040}$, then we have,

when $\alpha > \alpha_{040}$, r_w is convex with α, when α is assigned with interior solution, r_w reach the minimal value $r_w(\alpha_{04})$.

when $\alpha < \alpha_{040}$, r_w is concave with α, when α is assigned with corner solution, r_w reach the maximum value $r_w(\alpha_{040})$;

(ii) If $\alpha_{04} < \alpha_{040}$, then we have,

when $\alpha > \alpha_{040}$, r_w is convex with α, when α is assigned with corner solution, r_w reach the minimal value $r_w(\alpha_{040})$.

when $\alpha < \alpha_{040}$, r_w is concave with α, when α is assigned with interior solution, r_w reach the maximum value $r_w(\alpha_{04})$;

(iii) There is a critical value for $v = v_{02}$, when $v < v_{02}$, r_w is a decreasing function of β; when $v > v_{02}$, r_w is an increasing function of β.

Proposition 12. *Without constraints, the optimal financial strategy is r_w^*. When considering financial constraints, by financial constraints $\overline{\overline{B}}_w$ and when the constraint is tight, the corresponding interest rate is r_{w2} and the optimal interest rate is r_w^*, and $r_w^* \leq r_{w1}$.*

Corollary 11. *Given other parameters, there is a threshold $\alpha = \alpha_{050}$ for $(d^2 r_w/d\alpha^2) = 0$, and there is another threshold $\alpha = \alpha_{05}$ for $(dr_w/d\alpha) = 0$,*

(i) If $\alpha_{05} > \alpha_{050}$, then we have,

when $\alpha > \alpha_{050}$, r_w is convex with α, when α is assigned with interior solution, r_w reach the minimal value $r_w(\alpha_{05})$.

when $\alpha < \alpha_{050}$, r_w is concave with α, when α is assigned with corner solution, r_w reach the maximum value $r_w(\alpha_{050})$;

(ii) If $\alpha_{05} < \alpha_{050}$, then we have,

when $\alpha > \alpha_{050}$, r_w is convex with α, when α is assigned with corner solution, r_w reach the minimal value $r_w(\alpha_{050})$.

when $\alpha < \alpha_{050}$, r_w is concave with α, when α is assigned with interior solution, r_w reach the maximum value $r_w(\alpha_{05})$;

(iii) There is a threshold for $v = v_{03}$, when $v < v_{03}$, r_w is a decreasing function of β; when $v > v_{03}$, r_w is an increasing function of β.

5. Discussion

To investigate the validation of the model conclusions, we conduct numerical simulation experiments to further analyze the impact of key parameters on supply chain decision-making and participants' profits. Meanwhile, based on the data of Hunan Chenzhou thermal power plants, the values of each parameter are as follows: $A = 1kw, \alpha = (0.01kw/\$), L = 6ERU, L_1 = 7ERU, L_2 = 2ERU, \beta \in ((1,30)kw/ERU)$, $v = 0.01, g = 0.12, \delta = 7kw, \delta_1 = 7kw, \vartheta = kw, \vartheta_1 = 2kw, \tau = 10kw, \tau_1 = 10kw, c_1 = (2\$/kw), c_2 = (2\$/kw), c_3 = (2\$/kw)$, $k = (0.1\$/kw), w_7 = (1\$/kw), R_1 = 1\,kw, R_2 = 1kw, w_2 = (20\$/kw), w_1 = (20\$/kw)$.

In Figure 2, blue, purple, yellow, and green are respectively used to denote the four scenarios: the power grid capital line is confirmed and only call is executed; the power grid capital line is confirmed and double options are executed; the power grid fund is of uniform distribution and only call option is executed, and the power grid fund is of uniform distribution and double option are executed. Figure 2 shows the changing of the power grid profit curve under the four scenarios. Given other parameters, with the increase of users' demand sensitivity to carbon emission reduction levels in the second scenario, the profit of the power grid π_{R-2} exceeds the profits in other scenarios so far

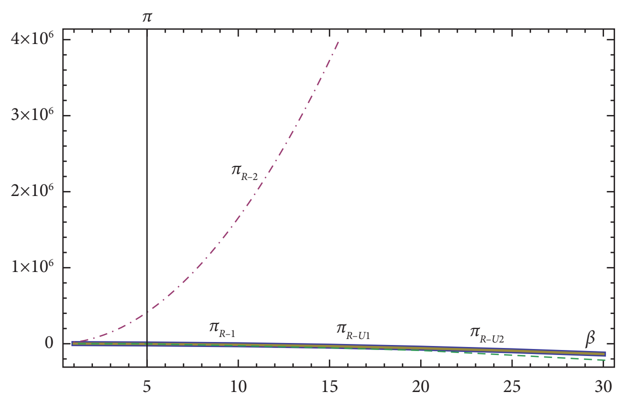

FIGURE 2: Impact of β on the grid profits under four situations.

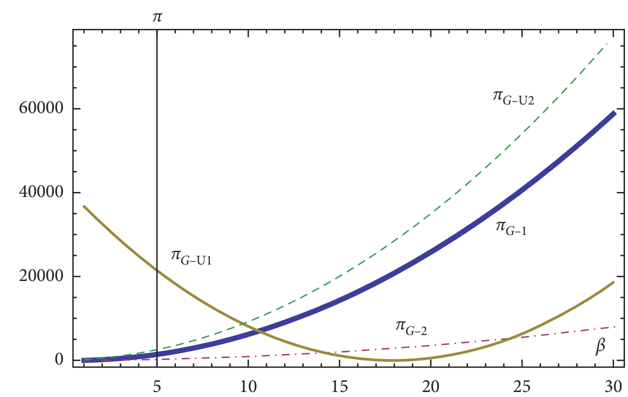

FIGURE 3: Impact of β on the traditional energy power plant profits under four situations.

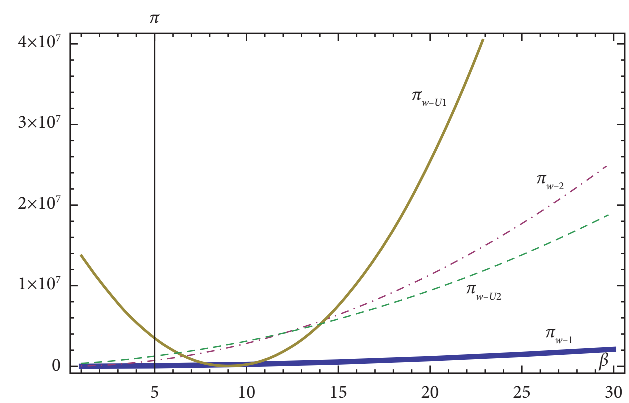

FIGURE 4: Impact of β on the wind power plant profits under four situations.

away as a new force emerges. The power grid profit curves under the other three scenarios tend to be bonded. It shows that when the power grid capital line is confirmed, the hedging strategy of executing a double option against disruption will be the most profitable choice for the power grid.

In Figure 3 shows that given other parameters, with the increasing carbon emission reduction level elasticity of demand, the profit of the traditional energy power plant is a convex function of β under the four scenarios. In β's value range for the curve π_{G-U1}, there is an intersection with π_{G-U2} and π_{G-1}, respectively. On the right range of the intersection of π_{G-U1} and π_{G-U2}, π_{G-U2} is at the top within this range. The put options execution is most beneficial to the traditional energy power plant as put option sellers. Moreover, due to the uniform distribution of the grid's funds, both of the CSE generation consumption and the power grid's capital budget can be promoted. That grid fund's dual impact will eventually act on revitalizing the traditional energy power plant profits. In contrast, when the grid's fund is confirmed instead of uniform distribution and has no impact on power users' consumption, the profit π_{G-2} is obviously at a lower level, which explains the important impact of power grid fund property on the traditional energy power plant. On the left range of the intersection of π_{G-U1} and π_{G-U2}, π_{G-U1} is at the top within this range. It illustrates that with the uniform distribution of the grid's fund, the options portfolio of executing a call and abandoning put is the most profitable scenario for the traditional energy power plant. There are two intersections with π_{G-U1} and π_{G-2}, respectively. π_{G-2} is at the top within this range between the two intersections. It illustrates that with the grid's confirmed capital line, executing the double option is most profitable for the traditional energy power plant. Whereas outside the range between the two intersections, when the power grid's fund follows the uniform distribution, executing the call but abandoning the put is most beneficial to the traditional energy power plant.

In Figure 4 shows that given other parameters, with the increasing sensitivity of users to carbon emission reduction level, the profit of the traditional energy power plant is a convex function of β under the four scenarios. In β's value range for the curve π_{w-U1}, it has two intersections with the other three curves, respectively. Between the range of all the two intersections for π_{w-U1} and the other three, π_{w-U1} is at the bottom. The execution of call options but abstaining from the put is most beneficial for the wind power plant when the grid's fund is of uniform distribution. On the outside space of the range between the two intersections, option impact (executing call but abstaining put) on the wind power plant is just on the opposite, and the wind power plant produces the most profit in this range. Between π_{w-U2} and π_{w-2}, there is an intersection point. The positions of these two curves show the power grid funds' impact on the profits of wind power plants under the same option strategy. When the power grid funds are uniformly distributed on the left side of the intersection point, it is more favorable for the wind power plant. On the right range of the intersection, it is more beneficial to the wind power plant when the grid capital is confirmed. The location of π_{w-1} has always been low, indicating that the first scenario is usually unfavorable to the wind power plant. Within the range between the two intersections of π_{w-1} and π_{w-U1}, π_{w-1}, it shows a weak advantage relative to π_{w-U1}. From the perspective of the wind power plant, with option portfolio (executing call but abstaining put), it is in the range of being outside of the two intersections for π_{w-1} and π_{w-U1} that emerges favorable condition to the wind power plant when the gird's fund is uniformly distributed.

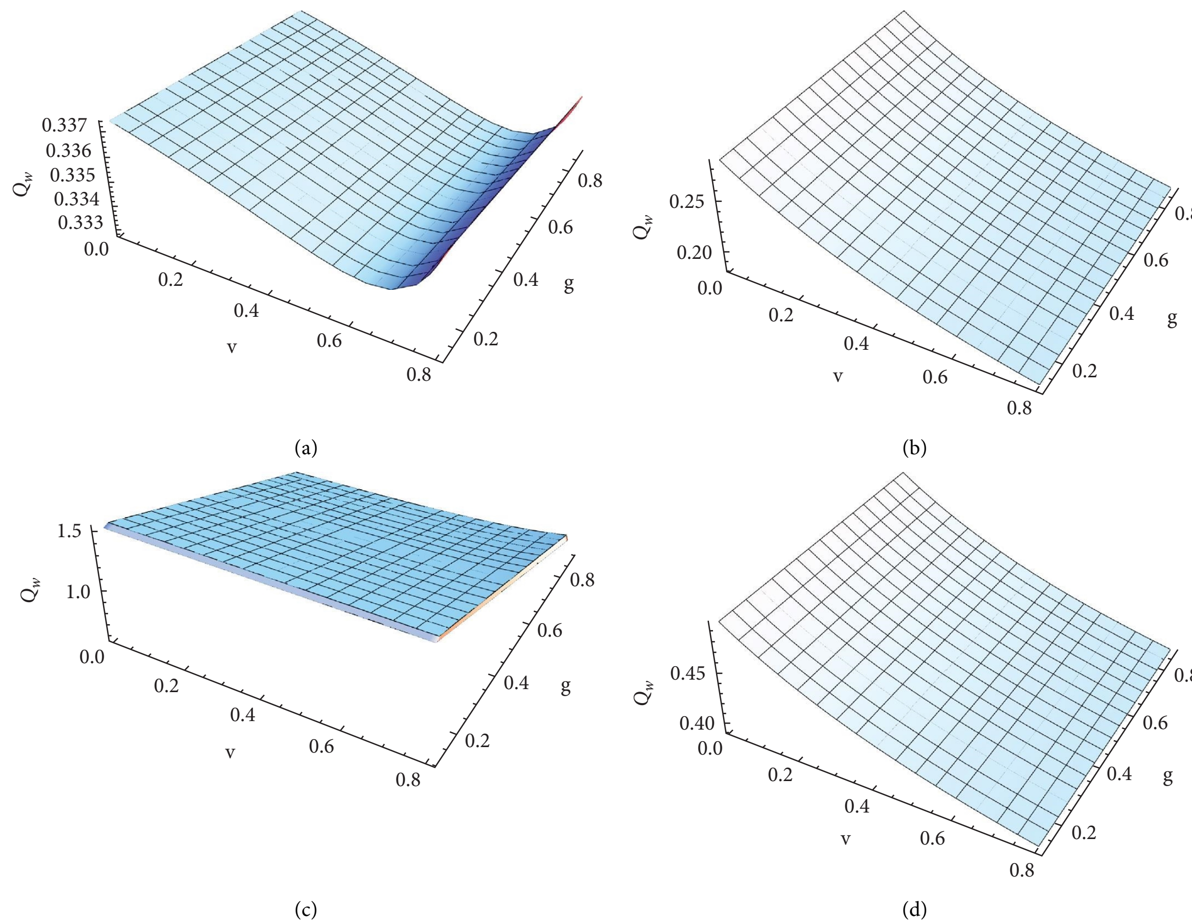

FIGURE 5: (a): Purchasing decision when power grid capital is confirmed and the call is executed. (b): Purchasing decision when power grid capital is confirmed and the double option is executed. (c): Purchasing decision, when power grid capital is of uniform distribution and only call, is executed. (d): Purchasing decision when power grid capital is of uniform distribution and the double option is executed.

In Figure 5 shows the impact of two key parameters impact on the procurement decision of the power grid under four scenarios, such as the wind yield rate and prepayment proportion to the traditional energy power plant. Figure 5(a) shows that when the grid's fund is confirmed, the wind power purchase initially decreases and then increases with the increase of wind yield rate when executing the call abandoning the put strategy. And it is not sensitive to the change in the payment proportion to the traditional energy power plant. Figure 5(b) shows that when executing the double option, the wind power procurement of the power grid with confirmed funds shows an obvious downward trend with the wind yield rate increasing, and is not sensitive to the change of the advance payment proportion to the traditional energy power plant. It shows that the higher the wind yield rate is, the greater the probability of executing the put. Executing the put option makes the power grid bear a higher risk of a wind power outage. Therefore, the power grid should adopt a more cautious procurement strategy when the wind yield rate is increasing. Figure 5(c) shows that when the grid's funds are uniformly distributed, the wind power procurement is not sensitive to the wind yield rate changing under call executing but abandoning put. With the increase in the proportion of advance payment to the traditional energy power plant, wind power procurement is reduced. This shows that with g increasing the amount of advance payment to the wind power plant is becoming less. So even if there is financing, it cannot stop the trend of reducing wind power procurement. Figure 5(d) shows that for the power grid with uniform distribution of funds, under double option executing, the wind power procurement volume shows an obvious downward trend with the increase of wind yield rate and is not sensitive to the change of advance payment proportion to the traditional energy power plant. Although the changing trend of procurement is similar to that in 5(b), the maximum procurement of wind power in this scenario is more than that in 5(b).

6. Managerial Insights and Practical Implications

There are differences in the wind power procurement decision-making with different option combinations, and the level of risk-reducing with wind power disruption is also different with option hedging strategies. If option hedging can reduce the disruption risk of electric-power supply to a greater extent, it will motivate supply chain firm managers to purchase aggressively. By comparing the benefits of procurement decisions with different option combinations, managers decide which option combination is more beneficial for them to hedge against the wind power supply disruption risk.

The debtor's (the power grid) funds property variation will enlarge the manager's purchase only on the budget side or on both manager's budget and user demand. However, the debtor should decide on the purchase while the creditors set credit interest rates considering the debtor's options strategy because different option combinations mean that the debtor bears energy supply disruption risks at a different level.

The two creditors have their strengths. One creditor can provide sustainable power generation energy (the traditional energy power plant) but will emit a large amount of carbon dioxide with power generation, resulting in environmental pollution. Under exerting a double option strategy, when facing sufficient wind, the creditor should compete for more orders by reducing credit interest rate with carbon emission reduction elasticity of demand. Inappropriate interest rates involve creditors in the predicament of coping with potential order loss; Or else, when facing the insufficient wind, this creditor should increase the credit interest rate with carbon emission reduction elasticity of demand to gain more benefit. In addition, the distinction of the grid funds property has an impact on the threshold of defining the wind yield rate. Under the option strategy of exerting call but abstaining put, instead of considering the wind yield rate, when in the higher range of carbon emission reduction level, the creditor should be fully prepared to compete for more orders through reducing credit interest rate with carbon emission reduction elasticity of demand; Or else, in the lower range of carbon emission reduction level, this creditor should increase the credit interest rate with carbon emission reduction elasticity of demand to gain more benefit. Here the grid funds property distinction also has an impact on defining the threshold of carbon emission reduction level.

Although the other creditor (the wind power plant) can provide CSE to ensure the prevention of carbon dioxide being released during power generation, CSE shows intermittence during electricity generation, which may cause electricity supply disruption. In this sense, when the power grid employs dual purchase, the two types of creditors are both complementary and competitive. The creditor with CSE should increase the credit interest rate with wind yield rate when facing sufficient wind while decreasing the credit interest rate with wind yield rate when facing insufficient wind. The two factors of the grid funds property and options strategy illustrate the impact on the threshold of defining the wind yield rate.

The two types of creditors acting as managers determine their credit interest rate by observing the decisions of other participants and find the most favorable situation by comparing the changes in profits in several situations.

7. Conclusions and Outlook

Over the past few years, supplier financing boosts economic growth taking the stand of purchasers. CSE has gained popularity among electric users and enhances low-carbon emission preference. The above two factors encourage economic growth from the perspective of environmental protection. But whether the introduction of CSE generation can help achieve the same operational and financial strategy remains unexplored in the literature. In this paper, we establish a Stackelberg game model consisting of two heterogeneous energy power plants, and a strategic power grid with capital constraints, in order to study the impact of different option hedging on the purchase of the power grid under supplier financing, and further investigate the power grid funds property's influence on participant strategies. From the model analysis, we obtain the following management conclusions to guide the development of the CSE generation business and supply chain financing improvement hoping to facilitate the electricity industry growth rapidly and healthily.

The results are as follows:

When the funds of the power grid are of uniform distribution, funds affect not only the power users' demand but also the power grid budget. High self-owned funds level or affluent credit line simulate the purchase volume. That is, the fund influence on power procurement decisions is illustrated by the above two aspects.

(i) When the power grid funds are to be confirmed, the price elasticity of demand shows monotonic on wind power purchase strategy; while when the power grid fund is of the uniform distribution, there is a threshold for payment to the traditional power plant. In the range of the payment lower than the threshold, wind power purchase has minimal value on the price elasticity of demand; whereas this payment is higher than the threshold, and wind power purchase has maximal value.

(ii) when the power grid funds are to be confirmed, under executing the call while abstaining the put, when carbon emission reduction level is high, the traditional energy power plant credit interest rate increases with a sensitivity of the power user to the carbon emission reduction level; under executing double option when wind yield is high, the traditional energy power plant's credit interest rate increases with a sensitivity of power user to the carbon emission reduction.

(iii) when the power grid funds are to be confirmed, under executing the call while abstaining the put when carbon emission reduction is at a high level, the wind power plant credit interest rate increases with a sensitivity of the power user to the carbon emission reduction level; under executing double option when wind yield is high, the wind power plant credit interest rate increases with a sensitivity of power user to the carbon emission reduction; when the power grid fund is of the uniform distribution, whatever option hedging, the wind power plant credit interest rate illustrates ambiguous relations with a sensitivity of user demand to the carbon emission reduction than that in funds are confirmed.

In addition, we find that the optimal wind power purchasing under supplier financing must surmount the purchasing amount without financing no matter whether the wind is sufficient or not. This implies supplier financing advantage over no financing scenario. The more sensitivity of the power user to carbon emission reduction, the higher of power user demand.

There are still some limitations in our paper, which could provide directions for future research. First, we examined solely supplier credit, which would be interesting when combined with the use of bank loans. To be specific, it is necessary to study if there is a third financial party such as a bank can provide credit together with power plants, and how can supply chain participants make decisions. Second, this paper assumes linear electric-power demand, but when demand is uncertain, the problem in this story will present another interesting scene. And we can also consider cost minimization as a novel bi-objective mixed-integer linear programming (MILP) model EB. Tirkolaee al et. (2020) [38], which is proposed FSS with an outsourcing option.

Data Availability

All data are given in the article file.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Guoshu Dong conceived the article. Both authors have contributed to writing, editing, proofing, and revising the manuscript. Conceptualization, Q.X. and B.X.; methodology, Q.X.; software, G.D. and B.X.; validation, Z.G.; formal analysis, G.D.; investigation, Z.G.; resources, G.D. and B.X.; data curation, G.D.; visualization, B.X. All authors have read and agreed to the published version of the manuscript.

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Research Article

Presenting a Fuzzy Multiobjective Mathematical Model of the Reverse Logistics Supply Chain Network in the Automotive Industry to Reduce Time and Energy

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The current research aims to design a fuzzy multiobjective model of the reverse logistics supply chain network in the automotive industry, taking into account the energy and time reduction approach. The automobile industry is one of the industries with a high demand worldwide. To continue the competition, the manufacturers of the leading car equipment should strive for better product quality by continuously improving their production processes, directing the production of greenhouse gases with low carbon levels, and increasing sustainability. In this regard, reverse supply chain networks and closed-loop chains have unique features that are very useful in the industry under review. The goal is to transform this model into a supply chain of a secure link in the automotive industry. Deterministic methods, genetic algorithm, particle swarm algorithm, and several scenarios with different aspects have been used to solve the model. The results show that the effectiveness of the three ways in terms of solution time is higher in the deterministic solution method. Proper use of the proposed process can help managers effectively manage the flow of recycled products concerning environmental considerations, and this process provides a sustainable competitive advantage for companies.

1. Introduction

The automobile industry is one of the industries with a high demand worldwide. This industry has long followed Henry Ford's approach based on economization, standardization, and product innovation and has progressed significantly. Today, cars are primarily mass-produced and have partial or even general renewals and the introduction of new models every few years on an annual or semiannual basis. Simple electronic devices in cars have given way to ubiquitous systems to improve the comfort, control, and safety of vehicles, all of which require careful integration into the manufactured car. All of these challenges does exacerbate by product customization to meet the unique needs of customers [1]. The primary motivating factor for companies to provide a new product or service is to pay attention to the different dimensions of the customer's demands and needs. Today, most car manufacturers have felt the need to have an optimal new product development process and have made many efforts and incurred considerable costs to have such a successful process [2].

The closed-loop supply chain involves the design, control, and implementation of a system to calculate the value during the life of a product by generating a dynamic value from different return products over time[3]. Conventional supply chain design practices look only in the direction of the forwarding flow. However, to benefit from return products, companies, in addition to direct logistics, also create reverse logistics, which cause the formation of a closed-loop supply chain [4, 5].

Meanwhile, the current situation of the automobile industry in the world shows that long-term contracts have increased, and the number of component manufacturers is decreasing. Also, competition has increased based on quality, engineering capabilities, and timely cut delivery. Therefore, parts and car manufacturers can create highly competitive supply chains through close cooperation and interaction [4, 6]. Therefore, one of the most critical research gaps in the country can be considered the interaction between the components of the supply chain and the discussion of competitiveness in the country's automotive industry. The automotive industry in Iran has had many ups and downs in the recent years. The year 1364 began with a decrease in foreign exchange earnings, signs of industrial, economic, and production crisis in the country's automobile industry, until in 1365, this industry, especially the Iran Khodro factory, was on the verge of closure. In the summer of 1991, due to the increase in the dollar rate and the tightening of sanctions, the production of cars by the Iran Khodro Company reached half compared to the previous year [6, 7]. In Table 1, the research model, target functions, established facilities, single or multiproduct, multiperiod, capacity limitation, and deficiency limitation of some past research studies are given.

Jabbarzadah et al. in an article entitled "Designing a closed-loop supply chain network under the distribution risks of a strong approach with a real-world application" state that the supply chain has become more vulnerable in today's global conditions and very unfavorable business conditions. In this paper, a simple stochastic optimization model is presented to design a closed-loop supply chain network that operates flexibly in the face of disturbances. In the proposed model, horizontal transportation was used as a reactive strategy to deal with operational and distribution risks. The goal is to minimize the facility location decisions and transportation side values, which constitute the total supply chain costs, across different distribution scenarios. The Lagrangian release algorithm is designed to solve the model effectively. Important managerial insights are derived from the implementation of the model in a case study of the glass industry. A horizontal shipping strategy can significantly reduce the cost of the entire supply chain. In addition, significant cost savings can be achieved by planning for distribution in the design of supply chain networks [4].

Considering the economic structure of Iran and the strategic position of the government in it, there are many problems in the country's automotive industry. These problems include the imposition of unilateral sanctions on the country, the occurrence of excess demand in the automotive market, the existence of multilateral monopolies among manufacturers, problems in the car pricing process, the lack of study and familiarity of consumers with customer rights, and a large number of small- and medium-sized manufacturing companies. It is parts. Planning to improve the technological capabilities of manufacturers in line with global developments [11] and more importantly, the inability of automotive manufacturers to supply the details they need, has necessitated the need to study the automotive industry. One of the innovations that today's manufacturers deal with, and at the same time, it can solve some of the problems of car manufacturers in supplying their parts, is the topic of proper disposal of vehicles and their recycling, which is in line with the resistance economy and self-sufficiency. It is primarily a car manufacturer. This research is an attempt made to present a model in this regard while reviewing the studies that are conducted in this regard at the world level. Now, the central question of this research is whether it is possible to take energy and time efficiency into account by designing a model of the reverse logistics supply chain network in the automobile industry. Also, the model considered in this research is a type of NP-hard problem, taking into account cost minimization (facility establishment costs and transportation costs), energy minimization along the way, and also considering the uncertainty in the demand for returned products, in which the time to solve the problem increases exponentially according to the dimensions of the problem. In general, the innovation aspect of this research can be seen in providing a multiobjective model according to the approach of optimizing cost and energy in the investigated industries. In this research, the researchers examine the problem from the two distinct aspects of cost and energy optimization in the automotive industry, while most researchers usually examine profit maximization.

2. Fundamentals and Theoretical Framework of the Research

The world is on a long-term strategy to achieve a climate-neutral economy. The Paris Agreement, adopted on December 12, 2015, sets the global consensus for international cooperation among countries to reduce carbon emissions [12]. At the same time, since the worldwide demand for transportation continues to increase, transportation is a significant contributor to greenhouse gas emissions. The automobile industry is one of the industries with a high demand worldwide. This industry has long followed Henry Ford's approach based on economization, standardization, and product innovation and has progressed significantly. Today, cars are primarily mass-produced and have partial or even general renewals and the introduction of new models every few years on an annual or semiannual basis. Simple electronic devices in cars have given way to ubiquitous systems to improve the comfort, control, and safety of vehicles, all of which require careful integration into the manufactured car. Likewise, fundamental changes in propulsion, from fossil fuels to electric (and hybrids in between), increase product complexity. These challenges do exacerbate by the need for variety and customization to meet unique customer preferences [13].

Meanwhile, electric vehicles reduce the impact of cars on the environment. Due to advanced programmability, autonomous vehicles can reduce road accidents, increase adequate road capacity, and reduce fuel costs. Some car manufacturers are developing the abovementioned technologies simultaneously in their product innovation, while some are innovating [14].

Table 1: Summary of several studies on reverse loop logistics.

Research studies	Types of logistics network	Models	Targets	Establishment of facilities	Multiproduct	Multiperiod	Capacity	Allowable shortage
Farrokh et al. [8]	Integrated	MILP[1]	Cost minimization	Factory of distribution/collection centers, recovery centers, and disposal centers	✓		✓	✓
Bashiri and Shiri [9]	Integrated	[2]SMILP	Cost minimization profit maximization	Collection centers factory	✓		✓	
	Reverse	MILP	Profit maximization	Reconstruction centers and inspection centers	✓	✓	✓	
Amin and Baki [2]	Integrated	MILP	Cost minimization	Production centers, collection centers	✓		✓	
Ashfari et al. [7]	Integrated	SMILP	Cost minimization maximizing customer satisfaction	Production/recovery centers and regional warehouse inspection/collection centers	✓	✓		✓
Zhou and Zhou [10]	Reverse	MINLP	Cost minimization	Recycling stations, recycling factories			✓	

[1]Mixed-integer linear programming. [2]Stochastic mixed integer linear programming.

One of the innovations that today's recyclers deal with is the proper disposal of vehicles and recycling. In this context, it is essential to emphasize the rapid increase in the demand for all kinds of auto parts and, as a result, vital materials such as cobalt, lithium, and nickel. For this reason, the significant challenges that drive automotive companies to increase the recycling of vehicle parts and equipment are the unavailability of raw materials, unbalanced supply, and demand, potential price increases, environmental impacts, human rights violations, and also raised political conflicts [14]. Therefore, these issues have increased the need to recycle and dispose of vehicles globally. The car is mainly composed of metal parts; unfortunately, the rest of the vehicle's recycling is transferred to the environment indefinitely. Thus, car recycling management becomes critical due to economic factors and environmental effects [11].

On the other hand, recent research has shown that remanufacturing has become more common in many industries due to its economic and environmental benefits. In addition, to protect the environment, many countries and regions have put forward requirements for product recycling, which turns production and consumption into a closed loop. However, forward and reverse supply chain design and interaction have challenges: in addition to meeting government recycling requirements, a closed-loop supply chain needs coordination to meet consumer's demand while meeting profit goals and achieving it [13]; as a result of the speed of technological development and economic growth, the rate of product substitution increases, which leads to an exponential increase in waste production. In reducing pollution and promoting resource reuse, collecting and reusing waste products are crucial, for which reverse logistics is essential [15]. A sustainable supply chain with proper and correct design causes minor damage to the environment. Reverse logistics in closed-loop supply chains by collecting and reusing used products in the forward direction are the best solutions for products with a limited life [16].

Therefore, reverse logistics is an environmentally friendly policy that helps protect the environment by reducing waste and pollution. In total, there are four different strategies for recovering used products. These four strategies are repair, renovation, reproduction, and recycling. Remanufacturing serves as the most crucial strategy to maintain the added value of products by giving a new life to used products. Also, remanufactured products can sell as products similar to a new development in the same or separate markets [17]. In general, reverse logistics starts with end users (first customers) where used products are collected from customers (returned products) and then attempts to dispose of end-of-life products through the decision various processes, including recycling (for raw materials or raw parts), refurbishing (for resale to secondary markets or, if possible, to primary customers), and repair (for sale in secondary markets through repair). Finally, some regular functional parts are used [18]. Now, according to the contents stated above, in this research, we are looking for the design of a fuzzy multiobjective model of the reverse logistics supply chain network in the automotive industry, considering energy and time efficiency plans.

3. Research Methodology

Figure 1 shows the closed-loop supply chain in the automotive industry [19].

The network does construct as a typical three-layer forward supply chain, namely, (1) supplier, (2) manufacturer, and (3) distributors and customers (wholesale and retail). Similarly, a three-tier structure does consider the reverse chain, including (1) vehicle delivery centers, (2) recovery centers, and (3) disposal and recycling centers. Usually, the reverse supply chain process starts with the customer going to the used car drop-off centers. The first reverse loop chain collects products from customers at delivery centers. After the initial examination, the repairable devices transfer to the recovery centers' repair facilities and the defective ones transfer to the disposal centers. In the recovery centers, suitable decisions are made based on the recycled product's type and quality and recycled items are classified. The recycled products are transferred to three locations: production facilities, disposal centers, and suppliers, based on the recovery decision. Some of the products at this stage transfer to the destruction department due to their nonrecyclability.

On the other hand, since some recycled products cannot be included in the production chain again by the manufacturer, completely healthy components are given to the suppliers. The final part of the repair and renewal operation in the reverse loop logistics cycle is assembling parts with new products (equal to the standards of new products). After quality control checks and packaging processes, these recovered products meet the demand of distribution centers and can sell to the customers at a discounted price. In the following, we will examine the research assumptions and present the mathematical functions of the investigation.

3.1. Hypothesis. In the first level of this chain, the raw materials necessary for factory production are provided by collection centers using recycled components. If recycling centers provide parts, factories can get the goods from foreign suppliers. The forward network consists of suppliers who supply various new features such as ferrous metal, rubber, primary parts, and batteries to manufacturers/distributors, where they transform into finished products (new vehicles). New cars are then distributed to user clusters. The reverse logistics network of return vehicles starts by receiving vehicles from user clusters at collection centers. Owners must return their vehicle to one of the collection or recovery centers. The next step is to transport the cars back to places of destruction or recovery. Used vehicles can be transported directly to unloading centers and pass through collection centers, recovery centers, liquids drain, and parts disassemble. Fuel, engine oil, transmission oil, hydraulic oil, coolant, air conditioning fluid, brake fluid, and steering fluid can be drained from end-of-life vehicles. While some

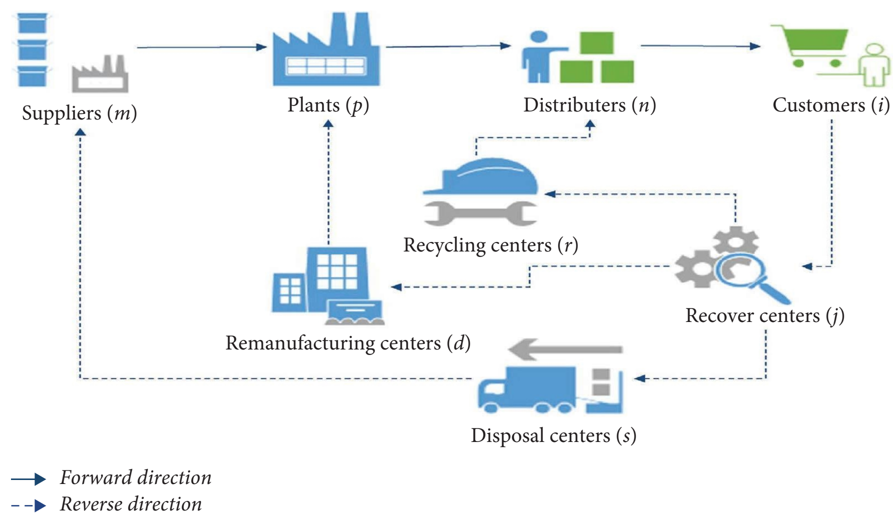

FIGURE 1: Closed-loop supply chain in the automotive industry.

components are sent to recyclers, the remaining is sent to shredders. In addition, reusable parts such as engines, differentials, transmissions, body panels (for example, hoods, doors, and bumpers) and wheels are resold to user clusters after restoration. After crushing, ferrous and nonferrous metals (aluminum, copper, zinc, and lead) are obtained. These materials are also sent for recycling. The sets, parameters, and variables of the model are listed in Tables 2–4, respectively.

The first objective of this research is to minimize costs. In the following, we will examine each of the expenses. The construction cost defines as an objective function, which is equal to the following:

$$\text{Construction} = \sum_{u\in U}\sum_{d\in D} f_d^u V_d^u + \sum_{u\in U}\sum_{j\in J} f_j^u V_j^u + \sum_{u\in U}\sum_{r\in R} f_r^u V_r^u + \sum_{u\in U}\sum_{n\in N} f_n^u V_n^u. \quad (1)$$

The cost of transportation of products during the reverse loop chain was defined as a function, which is as follows:

$$\begin{aligned}\text{Transportation} = {} & \sum_{t\in T}\sum_{u\in U}\sum_{s\in S}\sum_{p\in P} x_{sp}^u \text{di}_{sp} C_{spt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{p\in P}\sum_{p'\in P'} x_{pp'}^u \text{di}_{pp'} C_{pp't}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{p'\in P'}\sum_{d\in D} x_{p'd}^u \text{di}_{p'd} C_{p'dt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} x_{dw}^u \text{di}_{dw} C_{dwt}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{w\in W}\sum_{j\in J} x_{wj}^u \text{di}_{wj} C_{wjt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{j\in J}\sum_{r\in R} x_{jr}^u \text{di}_{jr} C_{jrt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{n\in N} x_{rn}^u \text{di}_{rn} C_{rnt}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} x_{rp}^u \text{di}_{rp} C_{rpt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{s\in S} x_{rs}^u \text{di}_{rs} C_{rst}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{d\in D} x_{rd}^u \text{di}_{rd} C_{rdt}^u. \end{aligned} \quad (2)$$

Then, the assembly cost function of the parts returned to the system was investigated.

$$\text{Assembly} = \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} Q_{rp}^u cr_{rpt}^u. \quad (3)$$

The function of the disposal cost of recycled parts was defined as that these parts can be imported to the destruction center from the recovery centers and used car delivery centers.

$$\text{Annihilation} = \sum_{w\in W}\sum_{u\in U}\sum_{t\in T} W_{p't}^u H_{p't}^u + \sum_{d\in D}\sum_{u\in U}\sum_{t\in T} W_{dt}^u \text{DH}_{dt}^u. \quad (4)$$

Furthermore, finally, the function of the penalty is the cost of delay of the product to the customer in the logistics chain. This function is defined as follows:

$$\text{Penalty} = \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} \text{Cd}_{dwt}^u D_{dw}^u. \quad (5)$$

Table 2: Introduction of sets and indices.

Symbols	Definitions
S	Set of fixed points for supplier centers $s \in S$
P	Set of fixed points for centers of producers $p \in P$
P'	Set of fixed points to create warehouse centers $p' \in P'$
W	Possible number of customers (retailers) $w \in W$
D	The set of potential points for distribution centers $d \in D$
J	The set of potential points to create collection centers $j \in J$
R	The set of potential points to create general recovery centers $r \in R$
N	The set of potential points to create $n \in N$ erasure centers
T	Period (t)
U	Number of products (u)

Table 3: Model parameters.

Symbols	Definitions
C_{sp}^{u}	The cost of transporting the product "u" from the suppliers to the centers of producers p
$C_{pp'}^{u}$	The cost of transporting the product "u" from the centers of producers p to the warehouse p'
$C_{p'd}^{u}$	The cost of transporting the product "u" from the warehouse p' to the distributor d
C_{dw}^{u}	Cost of shipping the product "u" from distributors d to customer w
C_{wj}^{u}	The cost of transporting the recycled product "u" from the customer w to the used car collection center j
C_{jr}^{u}	The cost of transporting the recycled product "u" from the used car collection center j to the recycling center r
C_{rn}^{u}	The cost of transporting the recycled product "u" from the recycling center r to the disposal center n
C_{rp}^{u}	The cost of transporting the recycled product "u" from the recycling center r to the production center p
di_{sp}	The distance from the suppliers to the centers of producers p
$di_{pp'}$	Distance from producer p to warehouse p'
$di_{p'd}$	Distance from the warehouse p' to distributors d
di_{dw}	Distance from distributors d to customer w
di_{wj}	Distance from customer w to the used car collection center j
di_{jr}	Distance from used the car collection center j to recycling centers r
di_{rn}	Distance from the recycling center r to disposal center n
di_{rp}	The distance from the recycling center r to the production center p
cr_{rpt}^{u}	The cost of assembling the returned product from the recycling center r to production center p in period t
$\mathscr{R}_{rnt}^{u}$	The return rate of the product u from the recycling center r to destruction center at location n in period t
$\mathscr{R}_{rst}^{u}$	The return rate of the product u from the recycling center r to suppliers s in period t
$\mathscr{R}_{rdt}^{u}$	The return rate of the product u from the recycling center r to distributor d
$\mathscr{R}_{rpt}^{u}$	The return rate of the product u from the recycling center r to manufacturers p
An_{n}	The capacity of the disposal center in product disposal
pc_{s}^{u}	Distributors' shipping capacity s
pc_{p}^{u}	Product production capacity u in the production center p
f_{d}^{u}	The fixed cost of building a distribution center on site d
f_{j}^{u}	The cost of building a collection and recovery center in the place j
f_{r}^{u}	The cost of building a recycling center on site r
f_{n}^{u}	The cost of building a burial and destruction center in the place of n
$H_{p't}^{u}$	The cost of keeping the product "u" per unit in the warehouse p' in the period "t"
DH_{dt}^{u}	Cost of holding the product "u" per unit at distributor "d" in the period "t"
Cd_{dwt}^{u}	The cost of late delivery of the car from distributor d to the customer w at time t
ϑ_{w}^{u}	The amount of demand for the product u by the customer w
$\mathscr{R}_{w}^{u}$	The return rate of the product u from the customer w

Table 4: Research variables.

Symbols	Definitions
x_{sp}^{u}	The amount of product flow u from the suppliers to the centers of producers p
$x_{pp'}^{u}$	The amount of product flow u from the centers of producers p to the warehouse p'
$x_{p'd}^{u}$	The amount of product flow u from the warehouse p' to the distributor d
x_{dw}^{u}	The amount of product flow u from distributors d to the customer w
x_{wj}^{u}	The amount of product flow u from the customer w to the used car collection center j
x_{jr}^{u}	The amount of product flow u from the used car collection center j to the recycling centers r
x_{rn}^{u}	The amount of product flow u from the recovery center r to the elimination center n
x_{rp}^{u}	The amount of product flow u from the recovery center r to the producer p
x_{rs}^{u}	The amount of product flow u from the recovery center r to the supplier s
V_{d}^{u}	=1 if the distribution center is at location d; otherwise, = 0
V_{j}^{u}	=1 if the center of the distribution is at location j; otherwise, = 0
V_{r}^{u}	=1 if the center of the distribution is at location r; otherwise, = 0
V_{n}^{u}	=1 if the center of the distribution is at location n; otherwise, = 0
$W_{p't}^{u}$	The inventory amount of product u in the warehouse p' at time t
W_{dt}^{u}	Inventory amount of product u at distributor d at time t
D_{dw}^{u}	The amount of product u from the distributor d that has not been delivered to the customer w
Q_{rp}^{u}	The amount of recycled product u from the recycling center r to the producer p

In general, the primary objective function whose purpose is to minimize costs is generally defined as follows:

$$
\begin{aligned}
\min Z = {} & \sum_{u\in U}\sum_{d\in D} f_{d}^{u}V_{d}^{u} + \sum_{u\in U}\sum_{j\in J} f_{j}^{u}V_{j}^{u} + \sum_{u\in U}\sum_{r\in R} f_{r}^{u}V_{r}^{u} + \sum_{u\in U}\sum_{n\in N} f_{n}^{u}V_{n}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{s\in S}\sum_{p\in P} x_{sp}^{u} di_{sp} C_{spt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{p\in P}\sum_{p'\in P'} x_{pp'}^{u} di_{pp'} C_{pp't}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{p'\in P'}\sum_{d\in D} x_{p'd}^{u} di_{p'd} C_{p'dt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} x_{dw}^{u} di_{dw} C_{dwt}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{w\in W}\sum_{j\in J} x_{wj}^{u} di_{wj} C_{wjt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{j\in J}\sum_{r\in R} x_{jr}^{u} di_{jr} C_{jrt}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{n\in N} x_{rn}^{u} di_{rn} C_{rnt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} x_{rp}^{u} di_{rp} C_{rpt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{s\in S} x_{rs}^{u} di_{rs} C_{rst}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{d\in D} x_{rd}^{u} di_{rd} C_{rdt}^{u} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} Q_{rp}^{u} cr_{rpt}^{u} + \sum_{w\in W}\sum_{u\in U}\sum_{t\in T} W_{p't}^{u} H_{p't}^{u} + \sum_{d\in D}\sum_{u\in U}\sum_{t\in T} W_{dt}^{u} DH_{dt}^{u} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} Cd_{dwt}^{u} D_{dw}^{u}.
\end{aligned} \tag{6}
$$

In examining the secondary objective of the research, it can say that this function is obtained from the combination and development of two models [3, 20]. This model makes efforts to minimize the total energy consumption during each production cycle. The two main activities that consume the most energy in producing a new product include the primary production and the production of raw materials by the supplier. Similarly, in the return loop, the energy produced during the reproduction of the product in the production line, and the production of new components requires the most energy. Since not all returned products can be recycled and used in reproduction, the nutritional components of the parts must be identified and sent back into the cycle. For example, in the case of engine parts of recycled cars, it is usually in the range of 50–90%. In this model, it indicates the company's ability to recycle the product (50–70% capacity). Now, according to the stated content, the total energy used in manufacturing and reproduction is as follows:

$$
\begin{aligned}
\text{Total Energy} &= T_{\text{man}f} + T_{\text{reman}f}, \\
\text{Total Energy} &= \left(E_{\text{sup}} + E_{\text{man}f}\right) x_{p'd}^{u} + \left(E_{\text{reman}f}\right) x_{rp}^{u} + \left(E_{\text{resup}}\right) x_{rs}^{u}.
\end{aligned} \tag{7}
$$

Therefore, the second function is as follows:

$$\min Z = \sum_{u\in U}\sum_{p'\in P'}\sum_{d\in D}\left(\mathrm{E}_{\mathrm{sup}} + \mathrm{E}_{\mathrm{man}f}\right) x^{u}_{p'd} + \sum_{u\in U}\sum_{r\in R}\sum_{p\in P}\left(\mathrm{E}_{\mathscr{R}\mathrm{man}f}\right)x^{u}_{\mathrm{rp}} + \sum_{u\in U}\sum_{r\in R}\sum_{s\in S}\left(\mathrm{E}_{\mathrm{resup}}\right)x^{u}_{\mathrm{rs}}. \tag{8}$$

Here, it is necessary to explain that the meaning of $\mathrm{E}_{\mathrm{sup}}$, $\mathrm{E}_{\mathrm{manf}}$, and ($\mathrm{E}_{\mathrm{resup}}$, and $\mathrm{E}_{\mathscr{R}sup}$ can be equivalent to the greenhouse gases emitted for moving a component between a factory and a warehouse or distributor ($\mathrm{E}_{\mathrm{manf}}$), ($\mathrm{E}_{\mathrm{sup}}$) between suppliers and the factory and in the reverse loop between the recovery centers and the factory ($\mathrm{E}_{\mathrm{remanf}}$), and between the recovery centers and suppliers ($\mathrm{E}_{\mathrm{resup}}$). Since most greenhouse gas emissions occur in the transportation and warehousing sectors, it is essential to include greenhouse effects in the supply chain/logistics models provided to reduce or control environmental losses from these companies. The global warming impact of this system is the result of greenhouse gas emissions through moving parts between factories and warehouses and between warehouses and retailers and greenhouse gas emissions related to product storage. Suppose ($eCo_{2p'pu}$) is the average carbon dioxide emissions associated with moving a component of product u between p factory and $\hat{p}'$ warehouse and ($eHFC_{p'pu}$) is the moderate gas leakage HFC per unit of product u between plant p and warehouse $\hat{p}'$, the combined global warming impact of both emitted gases is measured using the principle of equilibrium between the emission of one component of HFC and one $\mathrm{GWP}_{\mathrm{HFC}}$ unit of carbon dioxide, where $\mathrm{GWP}_{\mathrm{HFC}}$ is the global warming potential of HFCs described earlier. Therefore, $eCo_{2p'pu}$ is the amount of carbon dioxide equivalent to greenhouse gases emitted for the movement of a component between a factory and a warehouse calculated as follows:

$$eCo_{2p'pu} = \mathrm{GWP}_{HFC}\cdot e\mathrm{HFC}_{p'pu} + e\mathrm{Co}_{2p'pu}. \tag{9}$$

It is necessary to explain that based on the conducted tests, the graph of the average changes of CO_2 emitted from the exhaust of cars in 1995 and 1996 had a decreasing trend and reached 185.9 grams per kilometer from 189.25 grams per kilometer (gr/km) in 1995. In the eCO2jkl function, the function of the distance in the emission of greenhouse gases is considered. It is necessary to explain that the annual constant of CO_2 gas emissions is evaluated based on statistics 106 and HFC 107. In the following, we will examine the limitations of the model. These restrictions include the following:

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{dw} = \vartheta^{u}_{w}\forall w\in W, \tag{10}$$

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{wj} = \mathscr{R}^{u}_{w}\forall w\in W. \tag{11}$$

The two relationships between (10) and (11) guarantee that all customer demands an answer in the direct flow and all the returned goods collected from the customer centers in the return flow.

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{wj} = \sum_{r\in R} x^{u}_{jr}\forall j\in J. \tag{12}$$

Equation (12) ensures that all returned products are sent to recycling centers after the collection center.

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{rd} = \mathscr{R}^{u}_{rd}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r\in R, \tag{13}$$

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{rp} = \mathscr{R}^{u}_{rp}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r\in R, \tag{14}$$

$$\sum_{u\in U}\sum_{s\in S} x^{u}_{rs} = \mathscr{R}^{u}_{rs}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r\in R, \tag{15}$$

$$\sum_{u\in U}\sum_{n\in N} x^{u}_{rn} = \mathscr{R}^{u}_{rn}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r\in R.\forall u\in U, \tag{16}$$

$$\sum_{u\in U}\sum_{p'\in P'}\left(x^{u}_{p'd} + \mathrm{Q}^{u}_{p'd}\right) = \sum_{u\in U}\sum_{w\in W} x^{u}_{dw} - \sum_{u\in U}\sum_{r\in R} x^{u}_{rd}\forall d\in D, \tag{17}$$

$$\sum_{u\in U}\sum_{s\in S} x^{u}_{sp} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rp} = \sum_{u\in U}\sum_{d\in D} x^{u}_{pd} + \sum_{u\in U}\sum_{p'\in P'} x^{u}_{pp'}\forall p\in P, \tag{18}$$

$$\sum_{u\in U}\mathrm{W}^{u}_{p't} = \sum_{u\in U}\sum_{p'\in P'} x^{u}_{pp'} - \sum_{u\in U}\sum_{d\in D} x^{u}_{p'd}\forall p\in P, \tag{19}$$

$$\sum_{u\in U}\mathrm{W}^{u}_{dt} = \sum_{u\in U}\sum_{d\in \mathrm{PD}} x^{u}_{p'd} - \sum_{u\in U}\sum_{w\in W} x^{u}_{dw}\forall p'\in P'. \tag{20}$$

Equations (13)–(20) are related to the limits of flow balance in the nodes.

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{p'd} \leq \sum_{u\in U}\sum_{p\in P} x^{u}_{pp'} \forall p' \in P'. \quad (21)$$

Equation (21) guarantees that the amount of output from the producers' warehouse is less than the sum of the inputs to the producers' warehouse and is less than or equal to the sum of the information to the producers' warehouse.

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{sp} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rs} \leq \sum_{u\in U} \left(\mathrm{cap}^{u}_{s} + \mathrm{pc}^{u}_{s}\right) \forall s \in S, \quad (22)$$

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{pp'} + \sum_{u\in U}\sum_{p\in P} x^{u}_{p'd} \leq \mathrm{cap}_{p'} \forall p' \in P', \quad (23)$$

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{dw} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rd} \leq \mathrm{cap}_{d} V_{d} \forall d \in D, \quad (24)$$

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{wj} \leq \mathrm{cap}_{j} V_{j} \forall j \in J, \quad (25)$$

$$\sum_{t\in T}\sum_{u\in U}\sum_{p\in P} x^{u}_{rp}\mathscr{R}^{u}_{rpt} + \sum_{t\in T}\sum_{u\in U}\sum_{s\in S} x^{u}_{rs}\mathscr{R}^{u}_{rst} + \sum_{t\in T}\sum_{u\in U}\sum_{n\in N} x^{u}_{rn}\mathscr{R}^{u}_{rnt} + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D} x^{u}_{rd}\mathscr{R}^{u}_{rdt} \leq \mathrm{cap}_{r} V_{r} \forall r \in R, \quad (26)$$

$$\sum_{u\in U}\sum_{r\in R} x^{u}_{rp} \leq \sum_{u\in U} \left(\mathrm{cap}_{r} + pc^{u}_{p} V_{r}\right) \forall p \in P, \quad (27)$$

$$\sum_{u\in U}\sum_{r\in R} x^{u}_{rn} \leq \mathrm{cap}_{n} + \mathrm{An}_{n} V_{n} \forall n \in N, \quad (28)$$

$$\sum_{t\in T}\sum_{u\in U} W^{u}_{p't} \leq \mathrm{cap}_{p'} \forall p' \in P', \quad (29)$$

$$\sum_{t\in T}\sum_{u\in U} W^{u}_{dt} \leq \mathrm{cap}_{d} \forall d \in D. \quad (30)$$

Equations (22)–(30) guarantee current flows only between points where a facility is built, and each facility's total flow does not exceed its capacity.

$$\sum_{u\in U} V^{u}_{d} \leq 1 \forall d \in D, \quad (31)$$

$$\sum_{u\in U} V^{u}_{j} \leq 1 \forall j \in J, \quad (32)$$

$$\sum_{u\in U} V^{u}_{r} \leq 1 \forall r \in R, \quad (33)$$

$$\sum_{u\in U} V^{U}_{n} \leq 1 \forall n \in N. \quad (34)$$

Equations (31)–(34) guarantee that at least one of the potential centers is active.

$$\mathscr{R}^{u}_{rdt} + \mathscr{R}^{u}_{rpt} + \mathscr{R}^{u}_{rst} + \mathscr{R}^{u}_{rnt} = 1 \forall u \in U. \quad (35)$$

Equation (35) guarantees that the sum of the coefficients of the returned products is equal to 1.

$$V_{d} . V_{j} . V_{r} . V_{n} \in \{0 . 1\} \forall d \in D . \forall j \in J . \forall r \in R . \forall n \in N, \quad (36)$$

$$x^{u}_{sp} . x^{u}_{pp'} . x^{u}_{p'd} . x^{u}_{dw} . x^{u}_{wj} . x^{u}_{jr} . x^{u}_{rn} . x^{u}_{rp} . x^{u}_{rs} . W^{u}_{p't} . W^{u}_{dt} \geq 0. \quad (37)$$

Relations between (36) and (37) are logical and self-evident related to the decision variables of the problem.

In this model, the amount of product demand is considered fuzzy.

Various methods were proposed to consider uncertainties, including the application of fuzzy logic. In cases where the available information is ambiguous, the fuzzy set theory and fuzzy mathematical programming can be used to deal with real-world uncertainties. Uncertainty in the supply chain has been widely studied in the last decade. Various parameters cannot be considered inevitable in the real world and during a supply chain design. It is reasonable to include these uncertainties as much as possible to achieve more realistic results. It is necessary to understand the demand pattern to understand the changes in customer orders. Perhaps an essential principle in the supply chain is to focus on the demand to respond to them appropriately. Although the prediction of the product demand by the customer is generally not accurate, the complete satisfaction of the customer's order is of great value [21]. This research presents a fuzzy mixed integer linear programming model for designing a closed-loop supply chain network. Solving this type of model must first be converted into a deterministic model using the fuzzy number ranking method. It assumes that we have all available information about the product demand in a particular period. Since it is not always possible to fully satisfy customer demand, we use fuzzy logic to maximize the customer demand. Also, the maximum allowable supply order is limited based on the demand forecast. In this model, the amount of need for product u by customer $\mathbf{w}$ is represented by ϑ_w^u in period t. In this research, also due to the uncertainty of the cost of building recycling and collection centers, these two components, i.e., the cost of building a recycling center in place r (f_r^u) and also the cost of building a collection and recovery center in place j (f_r^u) is considered fuzzy.

3.2. Data Analysis and Research Findings. In solving the problems, different approaches are used, including solving by exact (deterministic) and experimental methods. In solving some problems, depending on the problem's complexity and a number of variables, it is impossible to solve those using exact approaches. Therefore, these approaches are called indeterminate problems in which the solution is not obtained through conventional techniques. It means that the answer can guess, and its validity is confirmed. These problems include complicated nonlinear programming problems. In solving these problems, some algorithms can provide acceptable results with good validity and optimization of outputs. The algorithms are called metaheuristic algorithms [4]. Since closed-loop supply chain problems are complicated, nonlinear programming problems and metaheuristic methods are used to solve this problem. In this research, cost minimization and energy consumption optimization requirements provide contradictory goals.

In this research, we use the particle swarm optimization method for its ease of implementation and ability to provide good convergence, maintain a proper balance between exploitation and exploration, and a multiobjective genetic algorithm. Among random algorithms, the genetic algorithm has high efficiency and has many applications. In addition to being used in design issues, the genetic algorithm is effective in various subjects such as function optimization, combined optimization, machine learning, decision processing, system segmentation, neural network training, and control systems, as shown [22]. In addition, the particle swarm optimization technique was used. Particle swarm optimization is a robust stochastic optimization technique based on the movement and intelligence of groups. This optimization algorithm is an accurate and low-cost innovative search method whose mechanism is inspired by the group behavior of biological populations. In the particle swarm optimization simulation, an external secondary table (reservoir) is used to store the information of representatives (particles) so that each particle can make the most of this information later. Also, this algorithm does equip with a particular mutation parameter that provides more and better search possibilities [4]. Since the general stochastic multiobjective programming model is present, it is a mixed integer two-objective problem. Its objective functions conflict with each other from the consensus programming method, one of the well-known decision-making methods. Multicriteria are used to solve problems with conflicting objective functions. In the first model, we name the first and second objective functions Z2 and Z1, respectively, and according to the above explanation, the proposed model must solve for both of these functions. Suppose that the optimal solution obtained for these two functions are Z_2^* and Z_1^*, respectively, in this case, the objective part of the Lp-metrics problem, which is named Z_3, is formulated as follows:

$$\text{Min}\, Z_3 = \left[\overline{\omega} \cdot \frac{Z_1 - Z_1^*}{Z_1^*} + (1 - \overline{\omega}) \cdot \frac{Z_2 - Z_2^*}{Z_2^*}\right]^P, \tag{38}$$

where the relative weight of the two-objective functions is Z1 and Z2 and shows the preference of the decision maker over the two-objective functions of the problem. Considering the objective function of Z3 and the limitations of the first extended stochastic model, a linear single-objective problem is obtained, which can be easily solved using software for solving mathematical programming problems (Mirzapour, Maleki, Ariannejad, 2011 : 135), and the p value specifies the degree of emphasis on existing deviations. Also, the metaheuristic algorithms did the program in the MATLAB R2016 software environment by a computer with an Intel® Core™ i5 CPU and 4 GB RAM. Then, to test the efficiency of the proposed algorithms, the results obtained from the deterministic method with the Gems software and the results obtained from the metaheuristic methods in small-sized examples have been compared with each other.

4. Research Findings

Ten problems with small, medium, and large dimensions are defined in Table 5.

Table 6 presents the nominal values of the parameters considered for solving the model.

This research uses three indicators of solution time, objective function value, and the gap between the accurate function values in two algorithms to compare the results of the two algorithms. The value of the objective function is the cost value obtained for the near-optimal solutions by each of the algorithms. The solution time in each algorithm is defined as the execution time of each algorithm to solve sample test problems and find the near-optimal solution. The third index to compare the two algorithms is the gap between the values of the objective function obtained by the two algorithms, which is calculated using the following formula:

$$\text{dev} = \frac{\text{Ans}(\text{PSO}) - \text{Ans}(\text{GA})}{\text{Ans}(\text{PSO})}. \tag{39}$$

This criterion is the gap between the particle swarm algorithm's objective function value and the genetic

Table 5: Generated example problems.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	15	1	12	2
2	4	2	4	10	70	20	2	15	3
5	3	3	8	15	90	30	2	18	4
5	3	4	10	20	100	50	5	24	5
8	4	4	11	22	120	52	5	27	6
8	4	5	12	25	150	55	5	30	7

Table 6: Nominal values of model parameters.

Parameters	Values
f_d	$U[400, 7000] * 1000000$
f_j	$U[100, 2000] * 1000000$
f_r	$U[2000, 5000] * 1000000$
f_n	$[2000, 2700] * 1000000$
$H^u_{p't}$	$U[50, 500] * 1000$
DH^u_{dt}	$[100, 700] * 1000$
$\underset{\sim}{Cd}^u_{dwt}$	$[60, 100] * 1000$
ϑ^u_w	$U[20, 4000]$
cr^u_{rpt}	$U[5000, 100000]$
$\mathscr{R}^u_w$	$U[0.2, 0.7]$
$\mathscr{R}^u_{rnt}$	$U[0.1, 0.8]$
$\mathscr{R}^u_{rst}$	$U[0.01, 0.2]$
$\mathscr{R}^u_{rdt}$	$U[0.01, 0.5]$
$\mathscr{R}^u_{rpt}$	$U[20, 4000]$
An_n	$U[2000, 6000]$
pc^u_s	$U[1000, 90000]$
pc^u_p	$U[1000, 100000]$
di_{sp}	$U[10, 250]$
$di_{pp'}$	$U[2, 15]$
$di_{p'd}$	$U[10, 500]$
di_{dw}	$U[0.1, 10]$
di_{wj}	$U[50, 300]$
di_{jr}	$U[10, 100]$
di_{rn}	$U[10, 250]$
di_{rp}	$U[10, 200]$

algorithm's accurate function value. In this research, to check the model's accuracy, we solve it with the deterministic method. The results of solving practical problems are presented in Tables 7 and 8. Table 7 shows the solving problems in small and medium dimensions.

Figure 2 results show that the efficiency of the three methods in terms of solution time is higher than the deterministic solution method. Also, among metaheuristic solution methods, the pso method is better than the genetic method in terms of efficiency and solution time. Then, we will examine the quality of the answers in three ways (Figure 3).

In the following, we will examine and compare the answers of the second model in all three methods (Figure 4).

The results show that the answer quality is more appropriate in the deterministic and metaheuristic solutions, and the outputs of the pso method are more suitable than the genetic method.

4.1. Sensitivity Analysis and Parameter Setting. The first step in applying and implementing a metaheuristic algorithm is choosing a method to display the answers. Converting a solution from the solution space to a chromosome is called encoding, and returning a chromosome to an explanation from the problem solution space is called decoding. The most important part of the genetic algorithm, which is considered its starting point, is this part. In providing the answers done by the chromosomes, the utmost care should be taken so that the chromosomes cover the possible space of the problem well. Then, we set the parameters of the research using the Taguchi method. To find the number of iterations, population size, and generally the adjustment factors of the genetic algorithm and the MOPSO algorithm, first run these algorithms for a problem with suitable dimensions under four scenarios according to Table 9 and analyze the results obtained and then the results. We use the Taguchi algorithm to adjust. In this method, we first normalize the obtained values of the objective function and then use the RPD method [21].

$$\mathrm{RPD} = \frac{|\mathrm{BestSol} - \mathrm{MethodSol}| \times 111}{|\mathrm{BestSol}|}. \tag{40}$$

The Taguchi method models the possible deviations from the target value and the loss function. To use the Taguchi method, we first calculate the number of times the algorithm does execute according to the defined factors and the number of scenarios. In this section, we use Minitab 17.1.0 software. According to the output of the software, since the test is performed for four factors in 4 different scenarios and also with the signaling method, the number of executions is equal to 32, the results of which are as follows (Table 10 and Figure 5).

According to the graph obtained from the experiments, the maximum signal-to-noise ratio for the npop parameter occurred at the fourth level (200), for the pc parameter at the third level (0.9), and for the pm parameter at the third level (0.3). Also, in the average graph, the minimum average occurred at the highest SNR levels. According to the test results, the algorithm's parameters can adjust as described. Any parameter whose value is higher in each level, that parameter is selected. In this section, there are eight scenarios for which we will examine the results (Tables 11–19):

(i) The first scenario is the effect of reducing the number of suppliers

Table 7: Solving problems with small and medium dimensions.

Problem numbers	GAMS			
	$Z1$	$Z2$	Z_{LP}	Time
1	80113284	$0.982452e^6$	0.0142	38
2	80308463	$1.021382e^6$	0.0153	59
3	80602724	$1.071815e^6$	0.0189	84
4	80681145	$1.092392e^6$	0.0204	123
5	80756941	$1.103849e^6$	0.0206	139
6	81082381	$1.109258e^6$	0.021	147
7	82183369	$1.061682e^6$	0.0192	265

Table 8: Computational results of solving the model with small and medium dimensions.

Numbers	(PSO)				Genetic algorithms				
	$Z1$	$Z2$	Z_{LP}	Time	$Z1$	$Z2$	Z_{LP}	Time	Dev%
1	80213561.6	$0.993394e^6$	0.016172	30.39	80012075.1	$0.983841e^6$	0.102114	5.41	0.08085
2	80684332.1	$1.020138e^6$	0.118273	48.58	80428613.8	$1.030593e^6$	0.151098	59.61	−0.0278
3	80695703.2	$1.074841e^6$	0.15742	14.89	80670872.4	$1.079542e^6$	0.165343	65.84	−0.005
4	80695638.9	$1.091239e^6$	0.15451	33.117	80688404.2	$1.10473e^6$	0.15064	3.124	−0.0956
5	80757659.3	$1.110258e^6$	0.33424	48.192	80826518.9	$1.119485e^6$	0839751	14.216	−0.01512
6	81082510.5	$1.113359e^6$	0.020759	27.361	82008390.7	$1.119468e^6$	0.067699	19.402	−0.02261
7	82193529.8	$1.065134e^6$	0.022115	64.480	83022644.4	$1.072373e^6$	0.028505	25.487	−0.0289

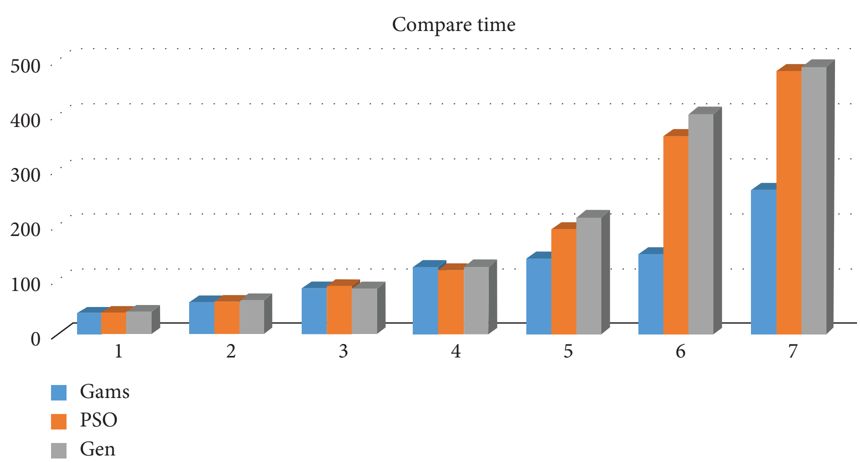

Figure 2: Comparing the efficiency of the three methods in terms of time.

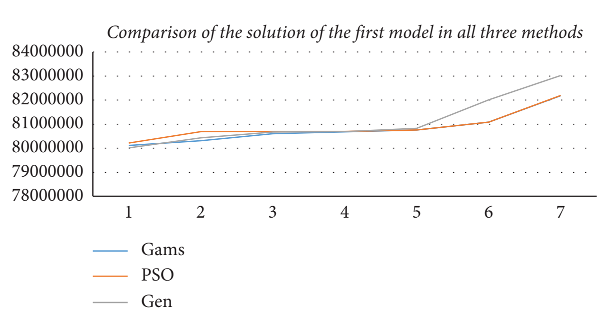

Figure 3: Comparison of the solution of the first model in all three methods.

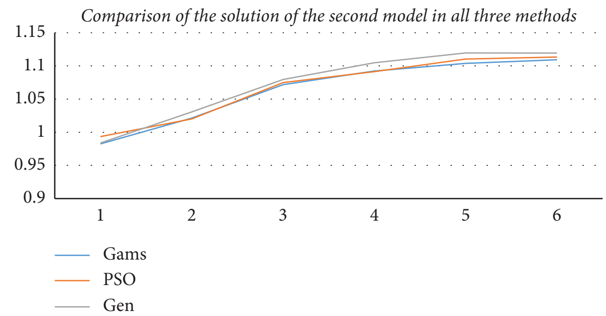

Figure 4: Comparison of the solution of the second model in all three methods.

Table 9: Search scope and the level of algorithm parameters.

Algorithms	Algorithm parameters	Parameter intervals	Down (1)	Average (2)	Average (3)	Top (4)
NSGA	nPop (A)	100–200	100	150	160	200
	Pc (B)	0.7–0.9	0.7	0.8	0.8	0.9
	Pm (C)	0.1–0.3	0.1	0.2	0.3	0.3
	nIt (D)	100–200	100	150	170	200

Table 10: Taguchi's test and the output.

Nos.	nPop (A)	Pc (B)	Pm (C)	nIt (D)	Results	
					*Z*1	*Z*2
1	100	0.7	0.1	100	80227060	98344239
2	100	0.7	0.1	100	80229536	99268691
3	100	0.8	0.2	100	80233727	98722769
4	100	0.8	0.2	150	80234949	98462359
5	100	0.8	0.3	170	80254504	99756076
6	100	0.8	0.3	170	80286119	98318166
7	100	0.9	0.3	200	80325805	98090332
8	100	0.9	0.3	200	80351272	98952117
9	150	0.7	0.2	170	80434591	98084387
10	150	0.7	0.2	170	80438102	99000841
11	150	0.8	0.1	170	80466134	98061798
12	150	0.8	0.1	200	80484707	99128316
13	150	0.8	0.3	100	80539193	99909096
14	150	0.8	0.3	100	80543857	98010037
15	150	0.9	0.3	150	80573897	98068655
16	150	0.9	0.3	150	80589294	99879789
17	160	0.7	0.3	200	80600242	98148621
18	160	0.7	0.3	200	80619278	99434486
19	160	0.8	0.3	170	80629699	98724094
20	160	0.8	0.3	170	80647873	99938537
21	160	0.8	0.1	150	80649432	99524111
22	160	0.8	0.1	150	80661124	98219896
23	160	0.9	0.2	100	80760872	99097960
24	160	0.9	0.2	100	80808109	99720353
25	200	0.7	0.3	150	80869951	99246520
26	200	0.7	0.3	150	80880755	99731871
27	200	0.8	0.3	100	80883344	98391865
28	200	0.8	0.3	100	80885121	98891820
29	200	0.8	0.2	200	80924294	99793848
30	200	0.8	0.2	200	80924898	98631582
31	200	0.9	0.1	170	80948812	99904995
32	200	0.9	0.1	150	80935738	99591277

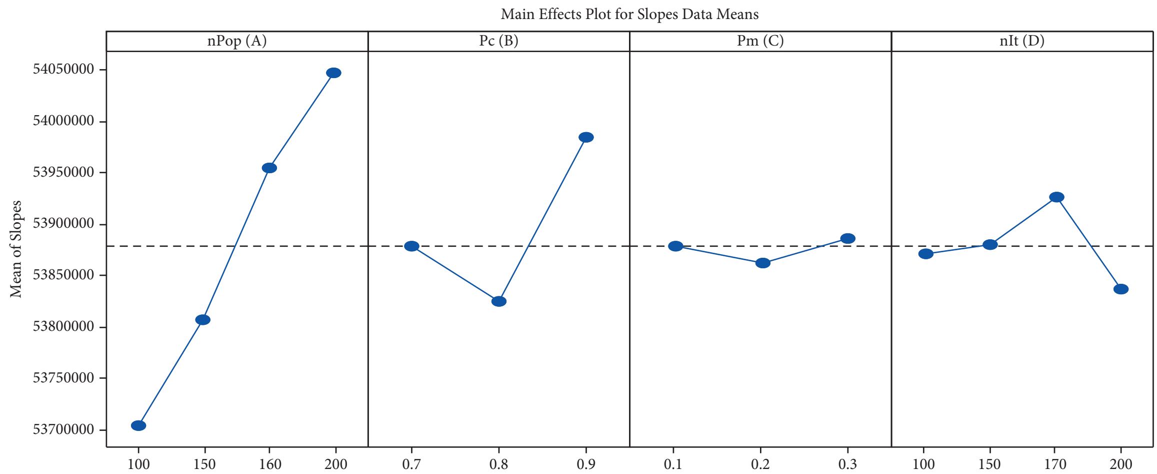

Figure 5: Taguchi output.

Table 11: First scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1–1
2	4	2	2	5	50	15	1	9	1–2
2	4	2	4	10	70	20	2	8	1–3

Table 12: Second scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	4	1	10	2
2	4	2	4	10	70	3	2	10	3

Table 13: The third scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	15	15	1	10	2
2	4	2	4	10	10	20	2	10	3

Table 14: The fourth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	2	20	5	1	10	4–1
2	4	2	2	8	50	15	1	10	4–2
2	4	2	4	12	70	20	2	10	4–3

Table 15: The fifth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	3	2	50	15	1	10	2
2	4	2	5	4	70	20	2	10	3

Table 16: Sixth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	15	1	10	2
2	4	4	4	10	70	20	2	10	3

Table 17: Seventh scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	3	2	2	5	50	15	1	10	2
2	2	2	4	10	70	20	2	10	3

Table 18: Eighth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
2	4	1	1	1	20	5	1	10	1
3	3	2	2	5	50	15	1	10	2
3	2	2	4	10	70	20	2	10	3

Table 19: Output of research scenarios.

Scenarios	$Z1$	$Z2$
1–1	80113284	0/982452e^6
1–2	80105136	0/982086e^6
1–3	80098180	0/981913e^6
2–1	80113284	0/982452e^6
2–2	80990713	0/982130e^6
2–3	80913915	0/9819881e^6
3–1	80113284	0/982452e^6
3–2	79394134	0/9821356e^6
3–3	78193421	0/9821267e^6
4–1	80113284	0/982452e^6
4–2	80308463	1/021382e^6
4–3	80602724	1/071815e^6
5–1	80113284	0/982452e^6
5–2	80164922	0/982672e^6
5–3	80193001	0/9829632e^6
6–1	80113284	0/982452e^6
6–2	80146279	0/982681e^6
6–3	80157909	0/982745e^6
7–1	80113284	0/982452e^6
7–2	77437918	0/971239e^6
7–3	74579130	0/959821e^6
8–1	80113284	0/982452e^6
8–2	81713046	0/982434e^6
8–3	82933801	0/982439e^6

(ii) In the second scenario, the effect of reducing the number of distributors

(iii) In the third scenario, the effect of reducing the number of customers

(iv) In the fourth scenario, the effect of increasing the used car delivery centers

(v) In the fifth scenario, the effect of increasing recovery centers

(vi) In the sixth scenario, the effect of the increase in used car disposal centers

(vii) In the seventh scenario, the effect of reducing the number of courses

(viii) In the eighth scenario, the effect of increasing the number of product.

According to the abovementioned scenarios, the results are as follows.

5. Conclusion and Suggestions

In this research, we will examine the minimization of costs and the requirements of optimizing energy consumption, each of which can provide contradictory goals. In this research, we have used the deterministic solution method using Gems software, optimization of particle swarm due to the ability of this algorithm to provide good convergence and maintain a suitable balance between exploitation and exploration, as well as a multiobjective genetic algorithm. Remanufacturing is an industrial process that restores used products to new conditions (quality, performance, and warranty equivalent to new products) through disassembly, cleaning, inspection, repair, replacement, and reassembly. Remanufacturing is critical to realizing a resource-efficient manufacturing industry and circular economy. Through remanufacturing, which plays a good role in promoting the developed producer responsibility system, waste products' performance revives and the new value is created. Products for remanufacturing are usually auto parts and electronic equipment, large machines, etc. Reverse logistics is closely related to remanufacturing. In many reverse logistics network studies of waste products, reproduction is a necessary research content.

5.1. Managerial Insights. In reverse logistics, the network structure mainly consists of consumers, collection centers, refineries, and markets. According to the product treatment method, reverse logistics can divide into different categories: remanufacturing, recycling, disposal, etc. Some reverse logistics remanufacturing uses hybrid facilities that integrate remanufacturing centers with production centers or some are based on distribution centers' collection centers [19]. However, one of the appropriate fields for integration in the closed-loop supply chain network is the integrated design of the direct and reverse supply chain, the fast loop supply chain, which can prevent the suboptimality caused by the different configurations of the natural and reverse logistics network. Considering that one of the components of social capital is the reliability and satisfaction of customers, the stability of the production line and the receipt of used cars and their recycling are among the components that can have a positive effect on social capital. Also, the social aspect was examined as the cost and benefits received by the customer for buying a new product, as well as their results from the consequences of the problem of waste disposal of waste products. Therefore, the effects of social capital are considered indirectly in the research model. This research presents a mixed integer linear programming model for designing a closed-loop supply chain network. In fact, in this study, we have introduced a multipart optimization model to check the efficiency of the closed-loop supply chain network. The model presented in this research is considered multiproduct and multicategory, which includes transportation costs and facility construction simultaneously.

6. Results

Considering cost minimization (facility establishment costs), energy minimization along the way, and the different demands of returned products, the desired model is a type of complex nonlinear programming problem in which the time to solve the difficulty increases exponentially according to the dimensions of the problem. In general, it should state that measuring a system's environmental and economic behaviors is very difficult due to the extent and complex nature of social and ecological issues. However, environmental and economic problems certainly affect the performance measures of a supply chain system. The analysis of this research shows that the limitation of carbon dioxide emissions is positively related to the benefits of the whole system. Therefore, decision makers may consider the emission of carbon dioxide despite the existence of carbon dioxide emissions to find a way to increase profits or reduce costs. Another critical issue identified in this research is creating synergies between different flows in the closed-loop supply chain. Traditional logistics networks were like a one-way street, while the chain closed loops of multiple internal and external flows cut the liver.

In this situation, using the potential of stream integration is an essential resource for saving the scale. The integration of the direct and reverse flow reduces overhead and total costs. In general, it can say that the proper design of a suitable closed-loop supply chain, especially in Iran's automotive industry, can lead to a reduction in production costs and even a reduction in the import of products that can be produced in the country, considering the current critical economic conditions of the country. It does not have and will lead to opportunities and significant growth to create more products at a more suitable price. In future research, researchers should identify different structures of reverse logistics reproduction and its efficiency. Also, develop a model using general conditions, time value of money, inflation rate, and tax rate. Another objective function can also consider minimizing the financial risk of the manufacturing company/customer. Also, other metaheuristic methods such as neural networks can be used in closed-loop supply chain modeling.

Data Availability

Data used to support the findings of this study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

The Role of the United States in the Relation between Iran and China as Two Key Members of the Asian Global Supply Chain

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With the birth of Fordism and the expansion of the markets beyond the states' borders, national supply chains have evolved into international and global supply chains. Some countries fared much better than others in becoming an irreplaceable part of the said chain. For instance, one could mention Iran due to its rich oil reserves and geopolitical position on the globe, China with its cheap human capital and high-profit margins, and the US with its massive reach all around the world. This study examines the US's mediatory effect on Iran-China's relations. Consequently, a derivative of the gravity model has been devised to test the said hypothesis. The dependent variables to test this hypothesis are China's imports from Iran and China's exports to Iran. The model controls the two states' currency value, their inflation rate, and the price of crude oil. Furthermore, the signing of the Joint Comprehensive Plan of Action in 2015 and the US's Maximum Pressure Policy in 2017 are the main variables of interest in the model in form of two dummy variables. The study employs a novel multidisciplinary approach both on the methodology front by introducing an abstract conception of distance and on the epistemology front by combining international economics literature with that of the international relations. According to the results, the US's foreign policy has a significant buffering effect on the trade between Iran and China. In other words, the United States acts as a distancing factor between the two states of Iran and China. This distancing effect, however, is stronger for China's imports from Iran in comparison to China's exports to Iran.

1. Introduction

The interconnected relations between the three states of Iran, China, and the United States cannot be fully explained by the two contemporary dominant schools of international relations, that is, neorealism and neoliberalism. For the past forty years, Iran has been challenging the US's role in the Middle East as the dominant ruler. Therefore, it seems to be a competition for control rather than for power which defies the main argument of the neorealists. Furthermore, the huge economic, political, and social costs that both sides have intestinally paid, over the course of the past four decades, suggest their lack of interest in absolute gains. In other words, neoliberalism seems to be unable to fully explain their relations as well. The same argument holds for the relations between China and the two other states.

When looked more closely, one could see that these intertwined relations are more of a social construct rather than anything else. For instance, the United States has used labels such as rouge state or supporter of terrorism to be able to exert its power onto Iran. On the other hand, the way the two states interact at the moment can only be fully grasped if looked at through history. What these two states mean to each other is actually the product of four decades of hostility. Even the presence of China in Iran as an ally, is a by-product of the two states common animosity towards the United States. Otherwise, China could gain much more from siding with the world's number one superpower.

For years, China has been trying to enter the Middle East, which is literally the center of the world, via different means. In 2015, it furthered its efforts to enter the region by introducing the Belt and Road Initiative; a massive infrastructural project which connects China to Europe via a land road and a maritime one, both of which go through the Middle East. For the project to succeed, China needs reliable allies in the region. Since Saudi Arabia is leaning towards the United States, Iran seems to be the best choice available. This option is more fortified given the severe sanctions the United States has directly and indirectly posed on Iran.

Given the interconnectedness of the relations between the three states, a close study of their relations is of utmost importance. That is exactly what this study hopes to achieve. These three states have a complicated and intertwined common history which makes their current interactions ever so interesting for scholars as well as policymakers. Since the financial crisis in 2007, China has deepened its footholds in the world economy as one of the economic superpowers of the century. It has also come under the United States' radar as a potential threat in terms of power (economic or otherwise). To continue on this path, China requires resources such as natural oil and gas. Iran having an abundance of natural resources plus its animosity with the United States makes it the best candidate for China's efforts to deepen its footholds in the Middle East.

Since becoming a rising superpower and a trading partner without alternatives, trade relations between China and other states in the international marketplace have become a hot topic of study in different disciplines such as marketing [1–4], economics [5–8], international relations [9–12], and even sociology and anthropology [13–15].

However, the said studies lack a multidisciplinary aspect. They each follow a single epistemological approach unique to their field of study [5, 6]. Moreover, the existing body of literature is either focused on China alone, or has a dichotomous point of view with China on one side and one or a bundle of states on the other [15], that fails to account for the supercomplex structure of the international system of states in the 21st century. Therefore, there is still a room for an interdisciplinary and multifaceted study of China's foreign trade relations. This study is endeavoring to take the first step on this road by studying the intermediary role of US foreign policies in the nature of China's trade relations with Iran. The evolution of the literature and its gap which the present study intends to fill is apparent in Table 1.

The present study wishes to evaluate the depths of China's footholds in Iran.

In order to do so, we have the following:

(i) Using the data on trade of goods and services between the two countries, it gives a chronological account of events which correlates with the trade between Iran and China as well as China and the United States

(ii) It will also give a brief description of the hostile relation which was built between Iran and the United States over the past four decades

(iii) Afterwards, using a derivative of the gravity model the role of the United States in the depth of the relation between Iran and China is examined

(iv) Furthermore, three scenarios are compared, as is, without the JCPOA, and without the MPP

(v) Finally, the concluding remarks are made

2. The Truel between Iran, China, and the US

This section provides a conceptual assessment of the triangular relationship between Iran, China, and the United States based on the concept of Truel. It was first introduced to the literature through a novel by Fredrick Marryat, Mr. Midshipman Easy. In simplest terms, it refers to a three-way duel where three shooters are aiming at each other and either one could fire at any of the other two. Whether the shot is successful or not is dependent on the shooter's accuracy, the number of available bullets, and the order of shooters. In a popular culture, the most common reference to the concept is a scene from the movie " The Good, The Bad, and The Ugly" where the three main characters of the movie face off, followed by a considerable suspension in which the three shooters decide on the right course of action in order to survive.

The concept entered the game theory literature through the work of Martin Shubik (1964, 43), "Game theory and related approaches to social behaviour," and the work of Richard Epstein (1967, 343), "Theory of Gambling and Statistical Logic." D. Marc Kilgour was among the first scholars who conducted extensive studies on different variations of Truel [16–19]. Following the earlier works on the subject, a Truel consists of at least three players, a sequence of shooting, and a probability of success which together form each player's strategy for survival. The common strategies are missing on purpose, or shooting to kill, and they depend on several factors such as each shooter's accuracy as well as their intention towards each other.

For the purpose of this study, the three countries of Iran, China, and the United States are considered as the three shooters. The model's assumptions are based on the cultures of anarchy introduced in Alexander Wendt's Social Theory of International Politics (1999, 254). Absent an authoritative body in the international arena of states define each pair of states that could be defined as an alliance, a rivalry, or an animosity. Allies are states which never resort to violence for resolving their differences. Moreover, whenever one ally is under attack by a third party, the other allies will go to its aid. Rivals are states which respect each other's right to sovereignty. However, the military conflict is not an impossibility when having disagreements. Finally, there are enemies who simply ignore, neglect, or outright deny each other's right to sovereignty.

The NATO members could be considered as an example of the first group; US-China relations could be considered as an example of rivalry; and the conflictual and violent

Table 1: Key previous studies.

Author(s)	Title	Epistemological approach	Year
Weisan	China's foreign trade marketing strategy: problems and prospects	Marketing	1987
Yu	Capital investment, international trade, and economic growth in China: evidence in the 1980–1990s	Economics	1998
Roy	China's foreign relations	International relations	1998
Shambaugh	China's international relations think tanks: evolving structure and process	International relations	2002
Liu et al.	The vegetable industry in China; developments in policies, production, marketing, and international trade	Economics	2004
Chan	A Chinese political sociology in our times	Sociology	2009
Sun and Heshmati	International trade and its effects on economic growth in China	Economics	2010
Fordham and Kleinberg	International trade and US relations with China	Economics	2011
Sutter	Chinese foreign relations: power and policy since the cold war	International relations	2012
Jiménez-Asenjo and Filipescu	Cheers in China! international marketing strategies of Spanish wine exporters	Marketing	2019
Santasombat	The sociology of Chinese capitalism in Southeast Asia	Sociology	2019
Gong and Nagayoshi	Japanese attitudes toward China and the United States: a sociological analysis	Sociology	2019
Karamoko et al.	International online shopping: countries' development level matter in marketing Chinese brands?	Marketing	2022
Shen et al.	Interaction between international trade and logistics carbon emissions	Economics	2022
Zhang et al.	How do the industrial structure and international trade affect electricity consumption? New evidence from China	Economics	2022
Liu and Faez	The role of the United States in the relation between Iran and China as two key members of the Asian global supply chain	International political economy	2023

relations between Iran and Israel, or China and Taiwan can be categorized as enmity. The said dichotomies could have three degrees of internalization; by force, by benefit, and by intrinsic belief. The first degree of internalization indicates that such a relationship is crucial for each side's survival; the second degree of internalization indicates that such a relationship is quite beneficial for each side; and the third degree indicates that such a relationship is intrinsically ingrained in the state's internal structure and culture. This is better shown in Figure 1.

Regardless of their relation, the states are all in pursuit of survival. However, the expected survival of each state is a combination of its relative power, the other states' relative power, as well as the nature of the relation between each duo. For an international system consisting of three states, this can be stated in the form of the following equation:

$$E(S_i) = P_i + \sum_{j=1}^{n-1} sgn_{ij} P_j - \sum_{j,k=1}^{n-1} sgn_{jk}\left(P_j + P_k\right), \qquad (1)$$

where $E(S_i)$ is the expected chance of survival for the state i, P_i is the state i's relative power, indicated as the probability of hitting the target, P_j and P_k are the state j's and state k's relative power, sgn_{ij} is the sign function which indicates the nature of the relation between the states i and j, and sgn_{jk} is the relation between the states j and k. The sign function takes three values of −1 for animosity and +1 for the alliance.

According to the equation system, each state's survival is a function of its relative power plus the other two states' relative powers weighted by the sign function which defines their relation with the main state, minus the combined relative power of the other two states weighted by the sign function which defines the relation structure of the other two states. Figure 2 is a schematic depiction of the abovementioned system for an international system consisting of three states with different relative power levels, two of which are allies and the third one is an enemy to the other two. Figure 2 shows a schematic representation of the abovementioned equation for a three-state case.

The figure includes three triangles for the three states of A, B, and C. The horizontal axis indicates the sign function of each duo's relation. The vertical axis is an indication of each state's relative power. The system consists of three triangular relations depicted in three different colors. Neither being one's own ally nor being one's enemy suggests that, for each triangle, the main state would be in the middle. Enemies would be positioned on the left side and the allies would be positioned on the right side of the figure. Based on the abovementioned figure and equation, each state's survival is the positive function of its relative power, a function of the other states' relative powers weighted by their relation structure with the main state, and a negative function of the combined relative power of the other states weighted by their relation structure. In the case of the three-state example, state A's survival is its relative power plus the relative power of its allies minus the combined relative power of the other two states. If the two are enemies, then their animosity will result in them distributing their resources to their rival and away from the rivalry with state A.

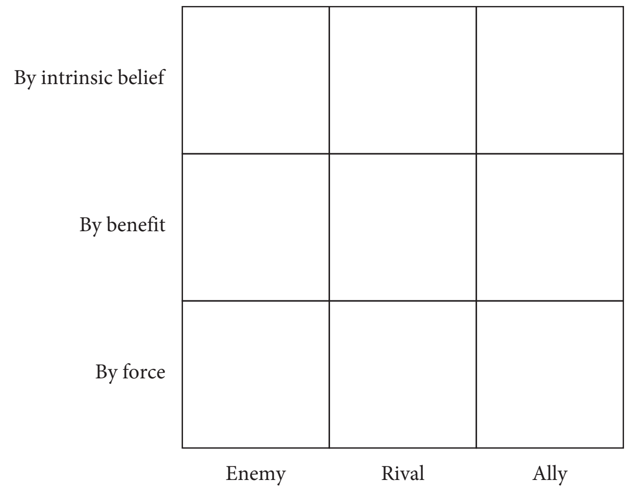


Figure 1: The cultures of anarchy ([20], 254).

3. Data

The data used for this study are extracted from the World Development Indicators [21]. The database is published by the World Bank and updated annually. The variables used for the study include the United States' GDP, China's GDP, Iran's GDP, their import of goods and services, and their export of goods and services. The time period of the study is 1979–2019. The reason for choosing this period, as explained in the following sections, is because the date is quite crucial for both China and Iran. The former got its global recognition after becoming the People's Republic of China and Iran became a democracy after 2500 years of the aristocracy.

Since the data used in this study constitute a time series, the first step would be to test the data for the existence of stationarity. The common way of doing so is by applying the augmented Dicky–Fuller unit root test [22]. Table 2 shows the result of the aforementioned test. As shown in the table, the key variables, natural logarithms of GDPs, exports, and imports, become stationary at the same level (one level of difference). Therefore, they can be used in an equation at the same level of difference. However, as it is indicated in Figures 3(a) and 3(b), the two dependent variables in this study (LEXPIRN and LIMPIRN) both exhibit a 1st autoregressive behaviour. Therefore, including an AR (1) coefficient in the model would improve its efficiency. Table 2 shows the results of the augmented Dicky–Fuller unit root test. Furthermore, the ACs and PACs for the study's dependent variables are shown in Figure 3.

4. Iran-China-US

In this section, the relations between the three states of Iran, China, and the United States will be evaluated in detail.

4.1. Iran and China. The time period of the study in this paper begins in the year 1979. There are two reasons for choosing this starting point. First, Iran's regime in this year changed from an aristocratic dictatorship to an Islamic republic through a people's revolution. Such a change came

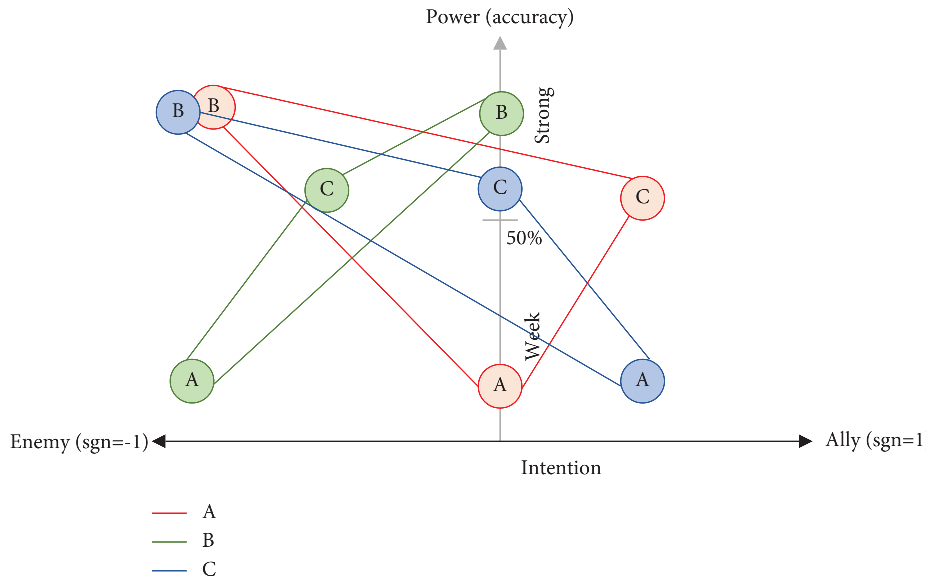


Figure 2: Schematic depiction of a Truel between the three states with three different relative power statuses.

Table 2: Augmented Dicky–Fuller unit root test.

Variables	The t-student Augmented Dicky–Fuller	1%	5%	10%	Trend and intercept	Difference level
GDPCHN	−6.31	−4.23	−3.54	−3.20	Trend and intercept	2
LEXPIRN	−2.93	−2.63	−1.95	−1.61	None	1
LIMPIRN	−4.76	−4.24	−3.54	−3.20	Trend and intercept	1
LGDPIRN	−6.83	−4.22	−3.53	−3.20	Trend and intercept	1
LGDPCHN	−4.74	−4.22	−3.53	−3.20	Trend and intercept	1

Source: estimations based on the data extracted from the World Development Indicators (2020).

with massive national and international complications for Iran. Internally, the newly found regime had to face several separatists revolting against it, combined with the numerous difficulties of reorganizing the bits and pieces of the previous regime. Internationally, while facing sanctions from the United States, Iraq invaded Iran, just one year after the 1979 revolution, a forced war which lasted till 1988 [24].

Second, China which is the other aspect of this study was internationally recognized after the communist party changed it from an aristocratic dictatorship to a communist country [25]. Consequently, as a new player in the international realm, China gained ever-increasing importance. The newly found regime, the People's Republic of China, had nothing in common with the previous regime which meant redefining every key institution anew [26]. This was difficult, especially since the international society took nearly six years to accept the new regime. In other words, 1979 was a key milestone for both Iran and China.

Having a common enemy made Iran and China perfect partners, their shared hatred for the United States pushed them towards one another. Therefore, as chart 1 depicts, over the past 40 years, Iran's share of the trade with China had an upward overall trend. However, if looked closely, this upward trend had numerous ups and downs. Moreover, these fluctuations are not the same for imports in comparison with exports. For the better part of the first period (1979–2000), Iran's imports from China in its total import surpassed Iran's export to China in its total export. The opposite seems to be true for the second period (2001–2019) [27].

According to section (a) in chart 1 until 1988, Iran was more of an importer from China rather than an exporter to it. This was most likely because during the eight-year war between Iran and Iraq, China was one of the few countries which was willing to support Iran's wartime needs. While the western states refused to partner up with Iran, China, having animosity with the West world, saw Iran as a suitable ally to stand up against the Imperialistic West. On the other hand, Iran, in deep need of support, began trading its oil with China's supplies for weaponry [28]. In 1979, Iran's import from China was less than 1 percent of its total imports. Till 1988, the figure went up to 1.3 percent. On the other hand, Iran's share of export to China in its total exports never surpassed 0.5 percent during this time. This was partly because the main exporting item was crude oil and during the wartime, its transportation faced many obstacles.

After the war between Iraq and Iran ended in 1988, there came the time for the restoration of all that was lost during the war. Many cities were heavily damaged and many people were misplaced. The constructions had to be restored and the people had to be relocated [29]. To do so, Iran required

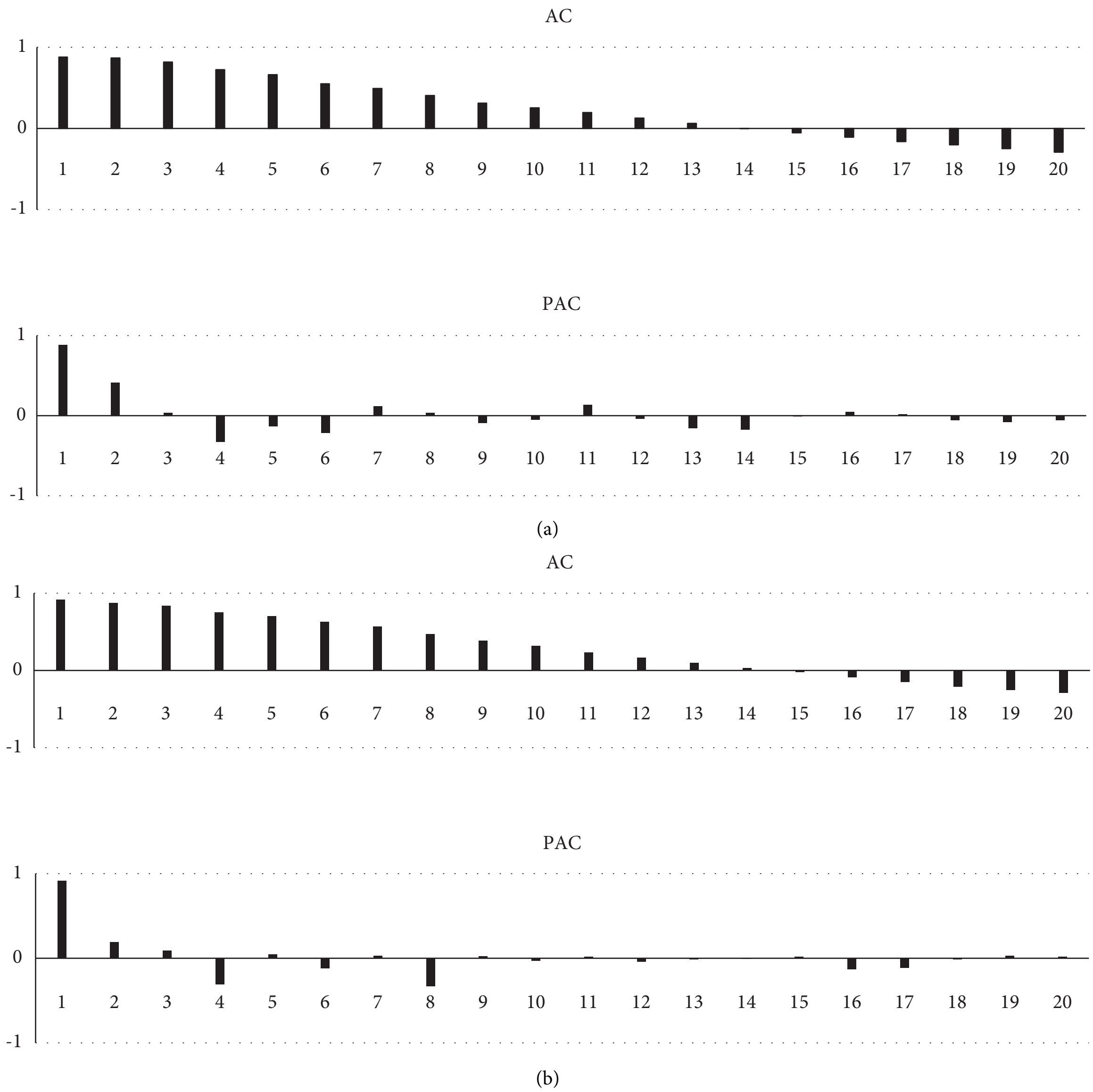


Figure 3: Correlogram of LIMPIRN and LEXPIRN with 20 lags at the level. Source: estimations based on the data extracted from the IMF direction of trade statistics [23]. (a) Natural logarithm of China's import from Iran (LIMPIRN). (b) Natural logarithm of China's export to Iran (LEXPIRN).

resources, many of which it did not have. Therefore, Iran's trade with foreign states increased. Consequently, so did its trade with China. This is one of the main reasons for the considerable increase in Iran's share of trade with China after 1988. Iran needed many items and only had oil to sell. This could be the reason for its import from China surpassing its export to China. However, with the end of the restoration phase in Iran, the time for Iran's modernization has come. China grasped the opportunity by partnering with Iran in constructing Iran's first subway line in Tehran [30].

According to chart 1, in 1999 Iran's share of export to China in its total export considerably surpassed its share of imports from China in Iran's total imports. In this year and henceforth, China's partnership with Iran evolved. Besides exporting various items to Iran, China began investing heavily in Iran's different sectors. As it seems, Iran paid for these investments with its endowment of oil. Little by little, due to severe international sanctions, Iran lost its other customers in the oil market. Therefore, China's share in Iran's export began increasing more or less constantly. While being a little under the share of export, Iran's imports from China followed the same trend. It seems as if Iran's relationship with China is similar to a barter economy in which Iran pays for its needs from China with its oil [31].

Since 1979 Iran has been under various severe sanctions; most of which were initiated by the United States and its allies. The main supporters of these sanctions were the western states. During the same time, China considered the West as its enemy and hence Iran as its ally. However, the signing of the JCPOA by the world's superpowers and Iran, expanded Iran's trading options [32]. Consequently, its share of export (import) to (from) China has decreased considerably since 2015. In the year 2017, however, President Trump left the JCPOA and introduced several new sanctions against Iran. This in turn, limited Iran's options for trade which again increased the share of Iran's trade with China and pushed it up to more than 40 percent in 2019 [33]. Figure 4 shows the trend in Iran's trade with China as the share of Iran's total trade for the period of 1979–2019.

4.2. Iran and US. While the two states of Iran and the US have considerable economic interactions with China, their relationship with one another is more political than economic. The first considerable interaction between the United States and Iran could be traced back to the final years of the Second World War. In 1941, with the help of its allies, the United States forced the reigning king of Iran (Reza Shah) out of his seat and gave the power to his son, Mohammad Reza Pahlavi [34]. His reign lasted until the revolution of 1979 which turned the 2500-year-old monarchy into a newly born democracy. During this time, Iran acted more like a colony for the United States. For nearly 30 years, the United States exploited Iran's natural resources, as well as its geopolitical position in the Middle East. Until in 1951, Iran's Prime Minister (Mohammad Mosaddegh) began the first steps of rebellion against the US by commencing the process of Iran's oil industry nationalization [35].

Since the efforts of Mosaddegh in preventing the US from exploiting Iran's endowments, the relationship between the states began to deteriorate. However, the first real hit to the relations between Iran and the United States was when through a people's revolution in 1979 [36], Iran's political structure went under massive modifications. In that year, Iran became the first Islamic democracy in the world and officially revolted against the hegemony of the United States in the region. The first act of animosity towards the United States was to take the American workers at the embassy hostage for 444 days [37]. It was the first time that the American officials (POTUS) put the stamp of Terrorism on Iran by calling the hostages "victims of terrorism and anarchy" [38].

Since the very first day of the Islamic republic of Iran's birth, the Iran-US relations have been deteriorating day after day. During the war with Iraq, Iran faced the first rounds of sanctions from the West [39]. It was accused of defying human rights in the name of war. As time passed the sanctions against Iran piled up and each had a different reason. For the past forty years, Iran has been accused of supporting terrorism, defying human rights, and pursuing nuclear weaponry. While none of these accusations have been proven, Iran has gone under several economic sanctions for each and every one of them.

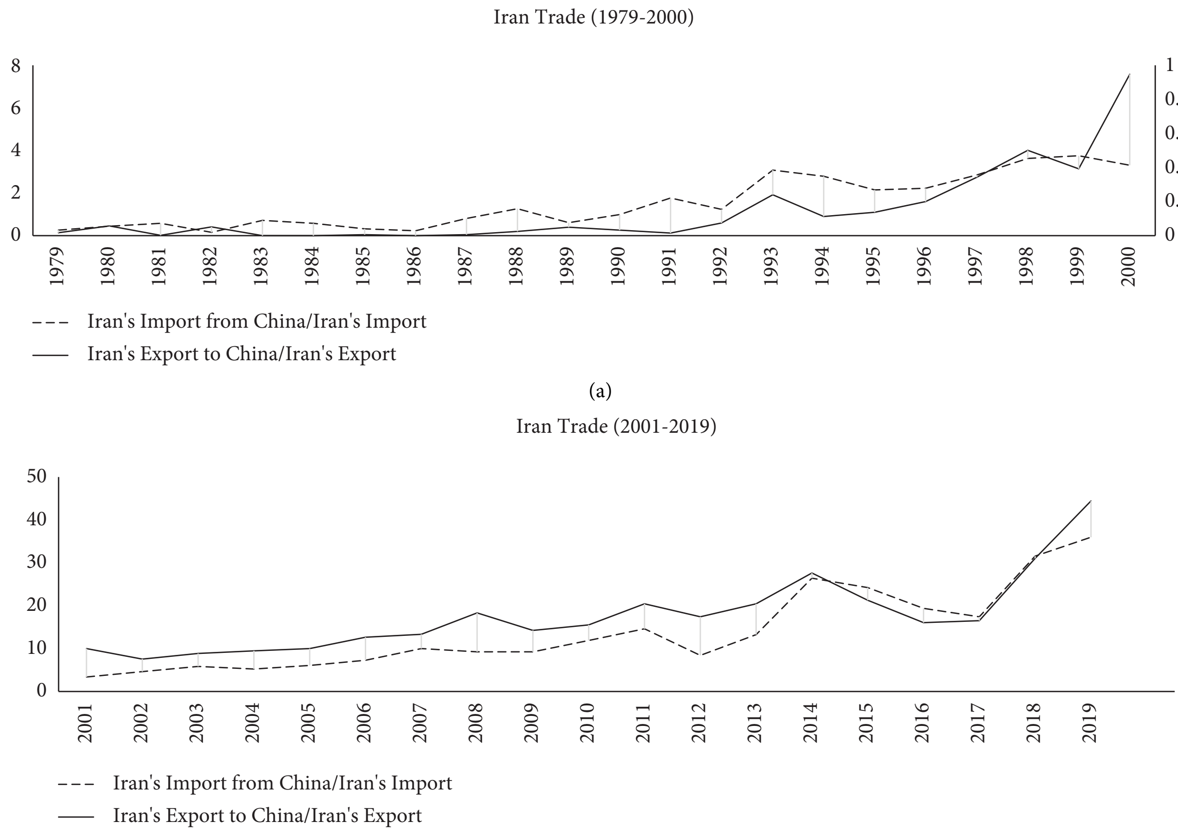
The well-known animosity between the two states is also quite obvious in the two countries' media. Over the past forty years, both the countries have held massive rallies against each other; they have also made several movies and TV shows which depicts the other side's intentions as negatively as possible. Furthermore, the two states' news outlets as well as their scientific circles describe the other side with words such as cheater, dangerous, and terrorist [40–42]. In sum, the relationship between the two states is anything but not friendly and it has been so for the past forty years. It seems that the two states have entered a game of power competition to gain the position of strength inside the Middle East. The winner of the game is yet to be determined. Its casualties, however, are quite considerable.

4.3. US and China. The relationship between the United States and the People's Republic of China since 1979 and up to twenty years before has been quite rocky. In the beginning years of the foundation of the People's Republic of China (1949–1971), their relationship was more or less hostile. This was partly because the US commenced the cold war with the USSR which was a communist state; the same as the PRC [43]. However, the USSR and the PRC soon parted ways and the US became the enemy of the China's enemy. This in China's mind is similar to a friend. In 1968, ending the Vietnam War, in which China and the US were foes, became the second milestone for a friendly relationship between the two countries. Finally, on 15 December 1978, the US officials announced the commencement of relations on 01 January 1979 [44]. However, given their twenty-year history of conflict, their friendship did face several challenges.

As the two sections of chart 2 depicts, the main period of volatility seems to last until the year 2000. Afterwards, China's trade with the United States followed a more or less smooth upward trend. In other words, it took around two decades for China and the United States to build a somewhat stable economic relationship. However, their political relationship, which can be traced on the news media, was much rockier. Its effects can also be traced in the development of trade between China and the US.

Up to the year 1979, the United States did not officially recognize the People's Republic of China. Therefore, the very little share of trade between the two states, as is shown in chart 2, seems reasonable. However, in 1979, the United States officially recognized the PRC; which explains the sharp rise in trade between the two states. It is worth mentioning that until 1989, China seemed to have little to offer to the United States. Therefore, imports from China were considerably less than exports to it. Also, they had little fluctuations, while export to China seems to have fluctuated heavily over the span of twenty years.

The trade between China and the United States seems to be more dependent on the political factors rather than the economic needs [45]. Almost every fluctuation in the US export to China seems to be parallel to a critical political event. For instance, the same year China and the United States disagreed on the US's arms sales to Taiwan, the US export to China dropped heavily (1982). On the other hand, as the US officials classified the PRC as a "friendly developing nation" in 1983, China began to buy more goods from the United States. In 1985, the share of the US export to China in its total export dropped considerably. Interestingly enough, it was parallel to the US's new protectionist legislations against China. The next big fall in the US export to



(b)

Figure 4: Share of Iran's trade with China in Iran's total trade (1979–2019). Source: the IMF direction of trade statistics [23]. (a) 1979–2000. (b) 2001–2019.

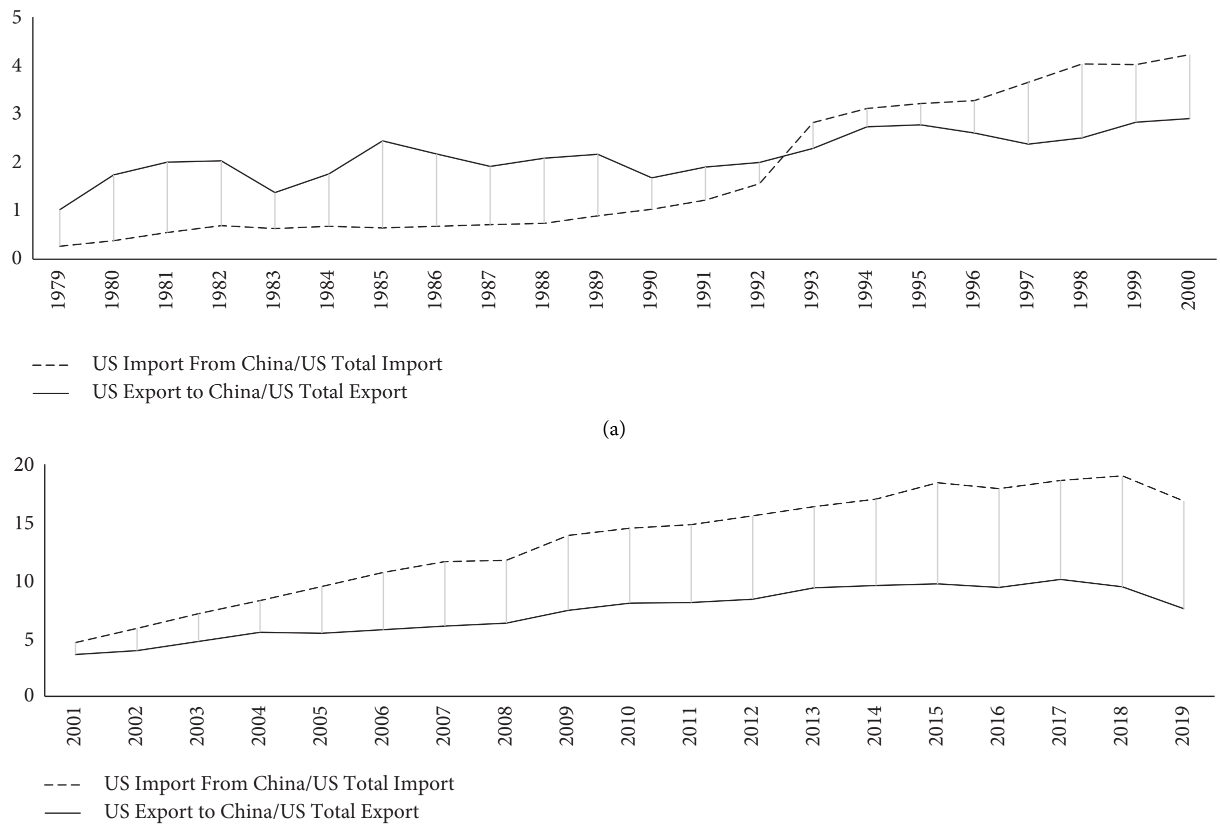
China was in 1989; the very same year the communist party massacred many students in Tiananmen. According to the data depicted in chart 2, the US punishing China for humanitarian crimes does not last more than a year. One year after each fall in the US export to China, the direction either changed or its intensity dropped considerably.

As is depicted in chart 2, the US import from China does not follow the same behaviour as the US export to China. Up to the year 1992, China was more or less a mere customer of American products. In 1992, however, the tides changed. Little by little, China accumulated capital and improved its industry. In 1992, as it shows in the chart, Chinese products did reach the level of international export. Therefore, the US imports from China jumped considerably and followed a much-sharped increasing trend. In just one year (from 1992 to 1993) the share of the US imports from China in its total imports, nearly doubled from 1.5 percent to 2.8 percent.

Since 1992–1993, China has become one of the key economic superpowers of the modern world [46]. As a result, its trade figures with the other superpower (United States) face less volatility since then. Even in 2007 and after the global financial crisis, the US trade with China did not drop. After a year or two, it even jumped up. The only considerable drop in the trade between the two states happened in 2015 which was the same year the JCPOA was signed and in 2018, which marks the beginning of the trade war between China and the US. Figure 5 shows the trend of the US's trade with China as a share of its total trade for the period of 1979–2019.

4.4. US-China Trade War. In 2018, the United States began imposing high levels of tariff on goods and services which were imported from China. The Trump administration accused China of conducting unfair trade practices and also not respecting the intellectual property rights of others. The United States objective for imposing such harsh policies against trade with China was twofold; on the one side, the Trump administration sought a reduction in the United States' trade deficit with China. Since Deng Xiaoping's reforms in 1992, the US's imports from China superseded its export to this newly found superpower. The trade deficit has been considerably negative ever since. Figure 6 shows the trend of China's total trade with the US for the period of 1979–2019.

This erratic behaviour of the Trump administration had many spill-over effects. For one, this full-on trade war with China hit the US consumers and farmers drastically. They were faced with financial hardships and higher prices due to this tit-for-tat policy. China also took considerable hits as well. Both its economy and industry lost the record high speed of growth they had for several years. To China, the United States was, is, and probably will be a huge customer.



(b)

Figure 5: Share of the United States' trade with China in the United States' total trade (1979–2019). Source: the IMF direction of trade statistics [23]. (a) 1979–2000. (b) 2001–2019.

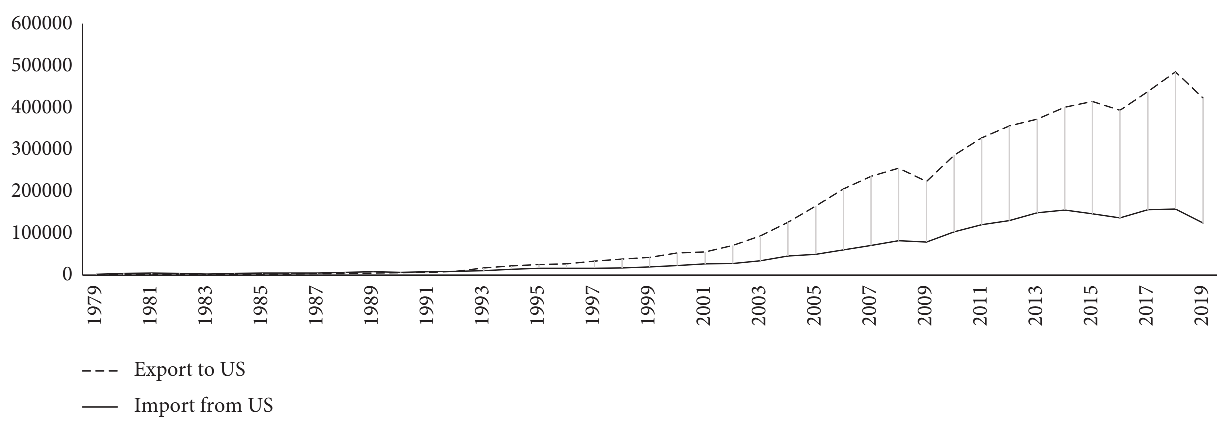


Figure 6: China's trade with the United States (1979–2019). Source: the IMF direction of trade statistics [23].

In other words, the sharp decline in trade with China in 2018 was a huge hit on both sides.

The trade war between China and the United States is not anything new. Despite many criticisms, this is not the first time the advocates of the free market and liberalism use tariffs and duties to exert their power and will onto other states. While probably not correct any more, there is ample evidence that in its infancy the western industrialization was built on the bricks of high tariffs and disrespect for intellectual property rights [47]. Indeed, those states that are preaching, such radical liberalist policies, got where they are now by doing the exact opposite. The United States is not an exception. The Smoot–Hawley act of 1930s is a good example of such behaviour.

During the late 1920s and early 1930s the Republican Party wanted to uphold its commitment to the agricultural sector in order to win more votes. Therefore, it supported increasing the average tariffs on dutiable imports from 38% to 45%. This action which only covered 1/3 of the US imports and merely amounted for 1.4% of the US GDP [48] was not a significant factor in pushing the US into the great depression [49]. It, however, was and is a good point of reference as a benchmark for bad state behaviour since 1930. It also showed some pull during the financial crisis in 2008.

The so-called Sino-US trade war since the 2018 followed three phases from the US side. On 22 January 2018, the US put global safeguard duties on imported solar panels and washing machines from China. It amounted to a USD of 10.3 billion [50]. Furthermore, on 01 March 2018, duties of 25% for steel and 10% for aluminium were introduced [50]. The excuse for doing so was to protect national security. Finally, on 06 July 2018, the USD of 34 billion imports from China faced 25% tariffs. The same amount was imposed on the USD of 16 billion goods and services on 22 August 2018. On 24 September 2018, the USD of 200 billion worth goods and services from China faced a 10% tariff which was increased to 25% by 10 May 2019 [50]. The excuse for such harsh treatment was China's violation of intellectual property rights.

China did not idly stand by while the US did whatever it wanted. The Chinese government paid back the American favors in full. China threatened to increase the duties on sorghum exports up to 178.6%. On 02 April 2018, China imposed duties on the USD of 2.4 billion worth of goods including aluminium waste, fruits, nuts, and pork. Later on, the USD of 34, 16- and 60-dollars' worth of imports went under 25% tariffs. On 01 September 2019, another USD of 75 billion went under the shadow of heavy tariffs. It included different brands of American cars and experienced a hefty rise in tariffs from 12.6% to 42.6%. This tit-for-tat behaviour in trade and tariffs continued until the WTO initiated some trade talks between the two states. As a result, China excluded the USD of 2 billion of goods from the tariffs; and the United States delayed the 5% increase in the USD of 250 billion goods from 01 October 2019 for 15 days. Figure 7 shows the share of the Sino-US trade war in the two states' bilateral trade since its commencement in 2018.

Overall, the Sino-US trade war cost the citizens of the two countries, USD 6.9 billion worth of welfare loss [51]. However, not everyone paid for the two superpowers fighting. For some countries this trade war was somewhat beneficial. The neighbor countries had less CO_2 emissions thanks to the reduced atmospheric transboundary transport. Furthermore, the war made other states more interesting as trading partners for China and the United States. As a result, many countries in the developing regions as well as in the Western Europe and Latin America experienced higher GDP growths after the war began [52].

5. The Empirical Model

5.1. Model. The model applied in this study is a derivative of the gravity model. It was extracted from the theory of gravity, by Sir Isaac Newton, from the school of physics. In physics, the gravity model indicates that the force between the two masses is directly proportional to their mass and inversely proportional to their distance. In other words, the closest the two masses are, or the heavier they are, the stronger the force between the two will be. In 1931, this way of thinking entered the realm of economics as the law of retail gravitation [53]. Later on, in 1962, according to Anderson and Van Wincoop [54], the concept was redefined and the use of the gravity model in the trade began. The basic depiction of the model is as follows:

$$F_{ij} = \frac{M_i^{\alpha} M_j^{\beta}}{D_{ij}^{\theta}}, \tag{2}$$

where F_{ij} is the force between the two objects, M is the size of objects i and j, D is the distance between the two objects, and α, β, and θ are the factorial components. The model has been used and devised in numerous studies to analyze the different issues. For instance, Alexander and Merkert [55] used this model to study the air traffic market in Australia. In doing so, they introduced attractions and impedance as the factors affecting the distance between the two points. While Alexander and Merkert [56] have used the gravity model to evaluate the dynamics of the aviation industry; others have used the model to evaluate other markets as well.

For instance, Natale et al. [57] have applied the same model to study the seafood trade. They have based their model on the idea that trade flows are proportional to the product of the economies of the exporters and the importers and inversely proportional to their geographical distance. While they used GDP as the factor for defining the size of each economy, others such as Matsumoto and Domae [58] augmented their models by including population and GDP per capita in theirs.

The variable for distance has also been modified based on the subject of the study. While many studies have taken geographical distance as the representative of distance in their models; some have taken a much more different path. For instance, Kuik et al. [59] have included the existence of a common tongue, past colonial relationships, regional trade agreements, and common borders as representatives of distance as well. They have taken into account the simple fact that due to the improvements in the transportation industries, geographical distance does not hold the weight it used to.

In this study, a new derivative of the model used by Porto [60] has been devised. The following table shows the variables used in this study as well as their unit of measurement. Table 3 provides an introduction of the variables used in this study.

The initial estimated equation is as follows:

$$TRADE_{CHN,IRN,t} = \frac{GDPIRN_t^{\alpha}.\, GDPCHN_t^{\beta}}{D_{CHN,IRN,t}^{\theta}}, \tag{3}$$

where TRADE is the amount of trade between China and Iran over a time span of t, GDPIRN is Iran's GDP over a time span of t, GDPCHN is China's GDP over a time span of t, and D is the distance between the two states of Iran and China over a time span of t. In order to be able to estimate a linear equation, the logarithm of the abovementioned equation must be taken. The result is as follows:

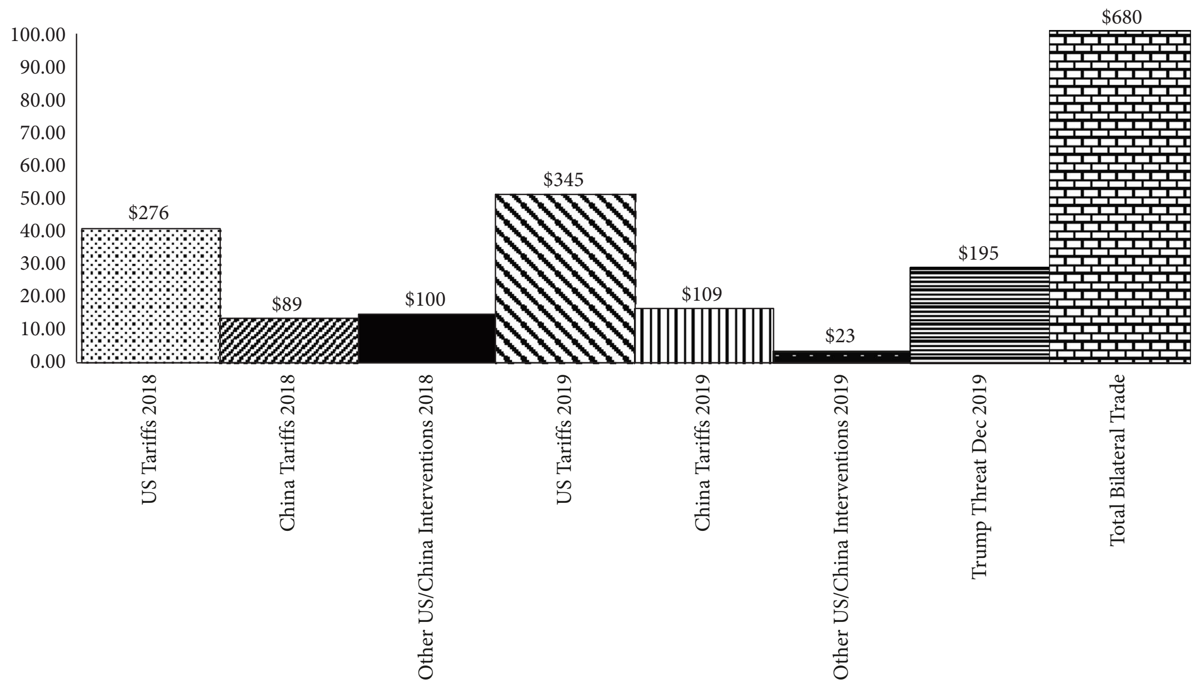


Figure 7: Share of the Sino-US trade war in total bilateral trade. Source: Evenette [49].

Table 3: The variables used in the model.

Variables	Explanation	Unit of measurement
Year	Year	Discrete
EXPIRN	China's export to Iran	Constant 2010 USD
LEXPIRN	Natural logarithm of China's export to Iran	Continuous
IMPIRN	China's imports from Iran	Constant 2010 USD
LIMPIRN	Natural logarithm of China's import from Iran	Continuous
GDPIRN	GDP of Iran	Constant 2015 USD
LGDPIRN	Natural logarithm of GDP of Iran	Continuous
GDPCHN	GDP of China	Constant 2015 USD
LGDPCHN	Natural logarithm of GDP of China	Continuous
JCPOA	The signature of the JCPOA (0 for before 2015 and 1 for after)	Dummy
MPP	The US leaving the JCPOA (0 for before 2017 and 1 for after)	Dummy
INFIRN	Inflation rate in Iran	Continuous
INFCHN	Inflation rate in China	Continuous
RIALUSD	Value of one Iranian Rial in USDs	USDs
YUANUSD	Value of one Chinese Yuan in USDs	USDs
OILPRICE	The price of each barrel of oil from Iran	USDs

$$LTRADE_{CHN,IRN,t} = \theta LD_{CHN,IRN,t} + \alpha LGDPIRN_t + \beta LGDPCHN_t. \tag{4}$$

The geographical distance between the two states in the study is in fact constant over time. However, as argued earlier, the distance between the two states has an intangible side. The purpose of this study is to assess the effect of the United States' foreign policy towards Iran on the said intangible side of the distance between Iran and China. Therefore, signing the JCPOA and the maximum pressure policy [61] are included in the model. The former represents a favorable policy (hence, lengthening the distance) and the latter represents a hostile one (hence shortening the distance). The result is as follows:

$$LTRADE_{CHN,IRN,t} = \theta LD_{CHN,IRN,t} + \alpha LGDPIRN_t + \beta LGDPCHN_t + \gamma JCPOA + \delta MPP, \tag{5}$$

where JCPOA is a dummy variable which takes 1 after 2015 when the deal was signed and 0 before the signing date; and MPP is a dummy variable which takes 1 after the US decided on leaving the deal in 2017 and 0 before the said date. The main dependent variables (China's export to Iran and China's import from Iran) which following the previous section has an AR structure. Furthermore, the two states' inflation rate and their currency value in USD are included as control variables. Moreover, considering the fact that Iran's main source of foreign currency is its export of crude oil and its products [62], the price of oil is also added to the model. Therefore, the final model is as follows:

$$\begin{aligned} LTRADE_{CHN,IRN,t} = {} & \theta LD_{CHN,IRN,t} + \alpha LGDPIRN_t \\ & + \beta LGDPCHN_t + \gamma JCPOA + \delta MPP \\ & + \varphi_1 INFIRN_t + \omega_1 RIALUSD_t \\ & + \varphi_2 INFCHN_t + \omega_2 YUANUSD_t \\ & + \rho OILPRICE_t + AR(1) + \varepsilon_t, \end{aligned} \tag{6}$$

where $\theta LD_{CHN,IRN,t}$ is the intercept, $\alpha LGDPIRN_t + \beta LGD PCHN_t$ is the effect part of the equation, $\gamma JCPOA + \delta MPP$ is the explanatory part of the equation, $\omega_1 RIALU\ SD_t + \varphi_2 INFCHN_t + \omega_2 YUANUSD_t + \rho OILPRICE_t$ is the control part of the equation, $AR(1)$ is an indicator of an autoregressive process (level 1), and ε_t is an error term with a constant variance and mean zero.

The main hypothesis in this study is the following:

H_0: the United States' foreign policy towards Iran has a significant effect on the trade between Iran and China

5.2. Results. In this section, the results from the estimation of the gravity model for the trade between Iran and China is discussed. The trade between any two states has two key aspects, that is, import and export. Thus, for the purpose of the research study, two different indicators were used as the dependent variable; China's imports from Iran and China's export to Iran. For each dependent variable three equations were estimated; one without including any indicator for the US's foreign policy towards Iran (EQ1); one with the signing of the Joint Comprehensive Plan of Action (JCPOA) as an indicator for the US's foreign policy in favor of Iran (EQ2); and another with the US's maximum pressure policy (MPP) as an indicator of the US's foreign policy against Iran. After the estimations, each equation was tested for the normal assumptions of regressions in terms of normality, heteroskedasticity, serial correlation, and autocorrelation. If any of them were not satisfied, the results were modified accordingly.

When using China's export to Iran as the dependent variable for controlling the two states' currency value, their respective inflation rate, and the price of oil, the first thing that comes to mind is the much higher influence of Iran's GDP on the dependent variable in comparison with China's GDP. A 1 unit of increase in Iran's GDP growth rate would result in 2.1 units of increase in China's export to Iran. That is while 1 unit of increase in China's GDP growth would result in a mere increase of 1.01 units of increase in its export to Iran. In other words, the bigger Iran's economy, the more China will export to it.

On the other hand, when considering China's imports from Iran which mainly consists of crude oil, the argument becomes reversed. 1 unit of increase in Iran's GDP causes 0.193 units of increase in China's imports from Iran. However, the coefficient is not statistically significant. On the other hand, the estimates suggest that 1 unit of increase in China's GDP causes 1.725 units of increase in China's import from Iran. In other words, China's import from Iran is significantly affected by the China's economy's size while not exhibiting any significant effects from the Iran's economy's size. One other point worth making here is that Iran's share in China's trade notwithstanding, is that it is not the only supplier of China's need for crude oil in the Middle East; nor is it the main one.

Economic sanctions are considered to be a less violent substitute for the war between states in which the imposing state isolates the target state by limiting the trade opportunities it could have [63]. In the current globalized economy, the only way sanctions could work is with an unshakable solidarity [64]. In other words, the imposing state needs support from other states, or at least those that matter, to be able to succeed in its policies toward the target country. Otherwise, the target state would simply find other trade partners. In other words, while sanctions limit the receiver's options, in the presence of what the literature labels as black knights [61], the extent of the sanctions' intended effect could be limited. The estimated coefficients for JCPOA and MPP act as an evidence for the said argument.

According to the results in Table 3, the signing of the JCPOA exhibits a significant decreasing effect on the trade between the two states in the study. The estimates suggest that the effect of the deal was considerably stronger in decreasing the growth rate of China's imports from Iran than China's export to Iran. Evidently, signing the JCPOA provided Iran with more options in terms of trade partners. However, the numbers suggest that Iran is more dependent on Chinese exportable goods and services than China is dependent on Iranian exportable goods and services. Consequently, Iran was able to find better costumers for its exportable goods and services.

The other aspect of the estimates, namely, the US leaving the deal which is popularly known as the maximum pressure policy (henceforth indicated as MPP), does not exhibit a significant direct effect on China's trade with Iran, either in the form of import or in the form of export. However, it seems to have had an indirect effect on Iran's trade with China through the effect of oil prices which is Iran's main source of foreign currency and international trade. In other words, while the initial estimates suggest no apparent effect for MPP on China's trade with Iran, further inspection suggests that MPP has affected Iran-China's trade relations through the change in oil prices. The output of the estimated equations is shown in Table 4.

5.2.1. Competing Scenarios. Given the statistical direct and indirect significance of the two main variables in the study, JCPOA and MPP, this section is dedicated to discussing three different scenarios; as is, without JCPOA, and without MPP. In other words, by using the estimated model three forecasts have been made for China's export to Iran and its import from Iran; the actual value, the value if the JCPOA

Table 4: The results of the gravity model.

Variables	LEXP						LIMP					
	1		2		3		1		2		3	
	Coef	S.E.	Coef	S.E.	Coef	S.E.	Coef	S.E.	Coef	S.E.	Coef	S.E
Constant	−76.802***	16.369	−93.223***	13.952	−76.520***	11.217	−51.352*	26.673	−88.037***	27.503	−50.870*	26.046
LGDPIRN	2.111**	0.941	2.284**	0.750	2.010**	0.681	0.193	1.299	0.496	1.109	0.084	1.277
LGDPCHN	1.011***	0.334	1.461***	0.336	1.096**	0.312	1.725***	0.510	2.809***	0.494	1.810**	0.544
INFIRN	−0.015	0.009	−0.012	0.007	−0.012	0.009	−0.038*	0.020	−0.034**	0.016	−0.036*	0.020
INFCHN	0.004	0.010	0.007	0.009	0.003	0.009	0.026	0.018	0.038**	0.014	0.025	0.018
RIALUSD	$-2.46E-06$	$3.53E-06$	$-3.20E-06$	$6.65E-06$	$-8.21E-07$	$5.16E-06$	$-3.61E-07$	$7.72E-06$	$-1.17E-06$	$9.90E-06$	$6.42E-07$	$1.28E-05$
YUANUSD	−0.092**	0.040	−0.194**	0.052	−0.104**	0.033	0.477***	0.094	0.253**	0.103	0.468***	0.093
OILPRICE	0.009**	0.003	−0.001	0.005	0.008**	0.003	0.027**	0.010	0.004	0.011	0.026**	0.010
JCPOA			**−0.664** **	**0.259**					**−1.621** **	**0.632**		
MPP					**−0.469**	**0.359**					**−0.336**	**1.202**
AR (1)	−0.069	0.160	−0.215	0.149	−0.211	0.149	−0.081	0.265	−0.236	0.218	−0.075	0.262
SIGMASQ	0.035	0.010	0.028	0.010	0.029	0.009	0.168	0.042	0.125	0.036	0.165	0.041
R-squared	98.80%		99.04%		99.03%		97.30%		98.00%		97.36%	
F-statistic	220.396		238.011		234.905		96.193		112.690		84.705	
Prob (*F*-statistic)	0.000		0.000		0.000		0.000		0.000		0.000	

***99%, **95%, and *90% degree of confidence. Source: research estimations based on the IMF data on the direction of trade [23] and the World Development Indicators [21].

Figure 8: China's export to Iran under different scenarios (1988–2019). Source: research estimations based on the IMF data on the direction of trade [23] and the World Development Indicators [21].

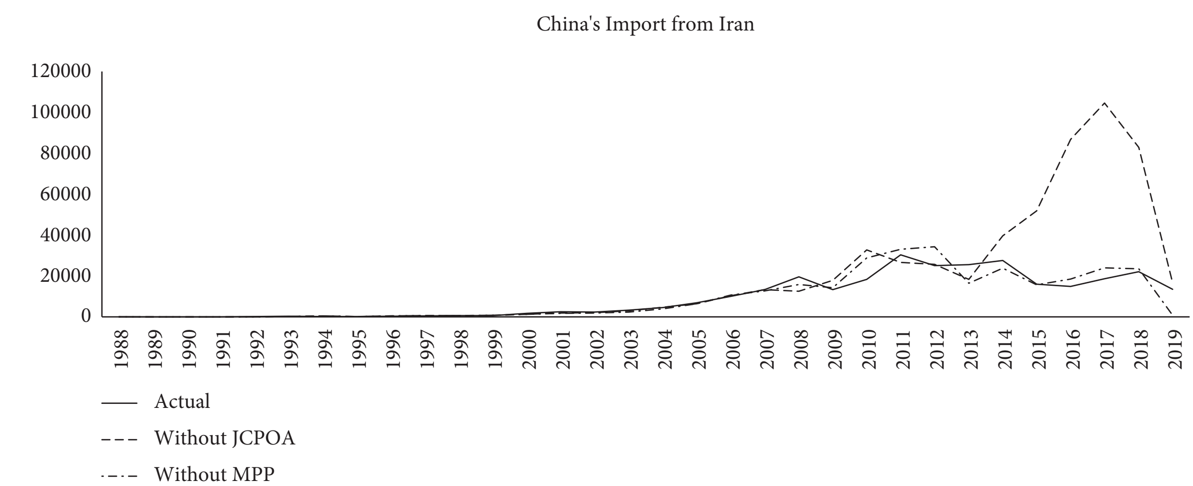


Figure 9: China's imports from Iran under different scenarios (1988–2019). Source: research estimations based on the IMF data on the direction of trade [23] and the World Development Indicators [21].

has not been signed, and the value if MPP has not been implemented. Charts 5 and 6 show the three scenarios for the period of 1988–2020.

According to chart 5, if the JCPOA has not been signed and the trend before 2015 has been continued, China's export would have increased considerably. However, as it is evident in the chart, the actuality of it is that China's export to Iran declined after the signing of the JCPOA. Furthermore, the MPP seems to be a policy which pushes China's export to Iran down; while in the scenario where the US does not leave the deal, China would export more to Iran.

On the other hand, according to chart 6, not signing the JCPOA would act as a considerable shock to China's import from Iran; making China one of the few viable customers for crude oil which is Iran's main exportable good. However, as the chart suggests, this shock is not sustainable and the value returns to the prior trend starting in 2017 and reaching the prior trend in 2019. Furthermore, the US not leaving the deal (MPP) does not seem to create a considerable change in the trend of China's import from Iran. In other words, as the results suggest, China kept a constant share of imports from Iran, regardless of the international political environment. Figures 8 and 9 show the simulated trend of China's export and import to and from Iran, respectively, for the period of 1979–2019.

6. Conclusion

6.1. Discussion. This paper is an attempt to shed some light on the role of the United States and its sanctions on the relation between Iran and China. The three states are the key figures in the current international supply chain. Therefore, the study of the three states' relations could prove fruitful in better achievement of the sustainable global supply chains [65]. In order to do so, the trade of goods and services between Iran and China was analyzed using a derivative of the gravity model. The signing of the JCPOA in 2015 and the US officially leaving the deal in 2017, popularly known as the maximum pressure policy (MPP) were introduced in the model as indicators of the US's foreign policy towards Iran; the former being a favorable one and the latter being a hostile one. The main hypothesis of this study was that the United States' foreign policy towards Iran has a significant effect on the relation between the two states of Iran and China.

Before estimating the main equation, a chronological account of the trade between Iran and China as well as between China and the US was given. According to the data on the trade between Iran and China, whenever the relations between Iran and the West were hazy, Iran and China increased their trade. This was more obvious when the US left the JCPOA in 2017. This may also be among the main reasons for the signing of a 25 year MOU between Iran and China in 2021. In the literature of international sanctions, they only succeed if there are no black knights to help the receiver evade the sanctions. The data clearly shows China to be such a knight for Iran.

The data on the trade between China and the United States bared some interesting fruits as well. While Iran seemed to have a somewhat balanced trade with China, the United States' share of imports from China, especially in the recent years, have surpassed its export to the country of dragons considerably. In other words, while Iran seemed to have bartered its oil for Chinese products; the United States evidently has failed in selling its products to China while being ever more increasingly dependent upon Chinese products.

The results of the gravity model clearly supported the research study's main hypothesis. According to the figures, the signing of the JCPOA had a significant buffering role with respect to the trade between Iran and China. Its negative effect seemed to be much stronger on China's imports from Iran in comparison to China's export to Iran. However, the US leaving the deal in 2017 seemed statistically insignificant in affecting China's trade with Iran. This notwithstanding, introduction of the MPP into the model showed an indirect effect on trade through changes in oil prices. The said results are summarized in the following list:

(i) While Iran seemed to have a somewhat balanced trade with China, the United States' share of imports from China, especially in the recent years, have surpassed its export to the country of dragons considerably

(ii) The signing of the JCPOA had a significant buffering role with respect to the trade between Iran and China

(iii) Its negative effect seemed to be much stronger on China's imports from Iran in comparison to China's export to Iran

(iv) The US leaving the deal in 2017 seemed statistically insignificant in affecting China's trade with Iran

(v) Introduction of the MPP into the model showed an indirect effect on the trade through changes in oil prices

In conclusion, this study has endeavored to evaluate and assess the relations between Iran and China and the role of the United States in the said relation over the past forty years. In order to do so, a chronological account of trade between the three states as well as a derivative of the gravity model was devised. Given the results, China has played the role of the black knight for Iran and helped it to stay above the water during the massive waves of sanctions. The US, however has had a significant buffering effect on China's relations with Iran.

6.2. Implications. The findings of the present study provide several implications both on the scholarly front as well as the policy front. To begin with, as far as the author's knowledge and search affords, this is the first application of the Truel game in this manner for such a topic. This could become the beginning of a new line of scientific inquiry in the fields of international relations as well as international economics. Moreover, the present study applies the gravity model in a different way than the previous studies. In here, the distance between the states is being treated as an intrinsic and abstract concept instead of a mere physical distance. This could also provide a new line of argument for evolving the gravity model.

On the other hand, the present study possesses explicit practical implications. In terms of policy formation, the findings provide evidence of how crucial sanctions-busting behaviors are in sanctions effectiveness. Therefore, while designing sanctions policies, the senders ought to take that into consideration. Using secondary sanctions could act effectively as buffers against such black knights. Furthermore, the targets which receive the threat of sanctions, could seek third-party supporters to mitigate the negative effects of the said threats on their economy, if they were to become realities.

6.3. Limitations and Suggestions for Future Studies. Although the authors tried their best to conduct a comprehensive study of the interactions between the three states of US, China, and Iran, there are aspects of the study which could benefit from further studies. First, this study applied a novel application of the gravity model. Since the data's nature is of the time series and given the substantial differences in the internal structures of the three states under study, it can be complemented with the application of a multifaceted time series model such as the structural vector autoregressive models (SVAR) or global vector autoregressive models (GVAR). Moreover, there is still a room to delve deeper into the game theoretical analysis of the three-player game (the Truel). The equation introduced here is still rudimentary and can indeed evolve into a more comprehensive equation if given enough due in future studies.

Data Availability

The data used in this study are extracted from the IMF direction of trade, World Bank's World Development Indicators, and Iran's national accounts. The complete references are available in the text under each relative table and figure.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Financing the Three-Tier Supply Chain: Advance Payment vs. Blockchain-Enabled Financing Mode

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Supply chain finance has shown remarkable results in alleviating the financial constraints of small and medium-sized enterprises. However, most studies have concentrated on the two-tier supply chain while ignoring the financing issues of the deep-tier supply chain. This study introduced the blockchain-enabled financing mode now utilized in the manufacturing industry and constructed a three-tier agricultural supply chain considering the farmer's financial constraints. The main contributions of this article are (1) presenting the blockchain-enabled financing mode in the three-tier agricultural supply chain and (2) investigating supply chain decision-making in the three-tier supply chain when the tier-2 supplier is financially constrained, comparing advance payment and the blockchain-enabled financing mode. Relevant parameter estimations were realized using the data of the last ten years, and numerical analyses were conducted. The results show that when the farmer's bank's financing capability exceeds the acquirer's, the farmer is motivated to select the blockchain-enabled financing mode. However, a win-win situation among the three-tier supply chain is only achievable when the transmission-fee rate falls within a particular range. In addition, if government agencies wish to promote blockchain technology by subsidizing blockchain-enabled financing, they might support the farmer in obtaining a bank loan at a cheaper interest rate. All members of the supply chain would benefit from this.

1. Introduction

Supply chain finance relies on the credit support of core enterprises to mitigate the risk resulting from information asymmetry [1]. It includes various financing options such as order financing and advance payment [2, 3]. They address the problem of "difficult and expensive financing" for new agricultural business entities in China by enhancing the bank's ability to finance capital-constrained subjects. However, approximately 20% of small and medium-sized enterprises (SMEs) can acquire loans (https://www.supplychainbrain.com/articles/32605-supply-chain-financing-for-us-mid-market-will-benefit-economy). And only financially constrained SMEs having a direct transactional relationship with the core enterprises in a multilevel supply chain are eligible for help. In the three-tier and even n-tier supply chains, most SMEs do not have a direct relationship with the core enterprise. According to Dong, it is a visibility barrier in *the deep-tier supply chain* [4]. Farmers in the agricultural supply chain are typically distant from the core enterprises in the deep-tier supply chain, making it difficult for them to benefit from traditional supply chain finance.

Blockchain technology offers novel solutions to the issues above [5–8]. In recent years, the government has provided numerous subsidies to encourage firms' adoption of blockchain technology. Local government departments (e.g., Kunshan, Jiangsu Province) are increasingly collaborating with core enterprises to overcome the visibility barrier in the deep-tiers supply chain. For instance, the "Simple Hub" product from TCL Group enables core enterprises to issue electronic debt flow certifications (also known as gold sheets) within the system. Those possessing gold sheets can apply for financing through the platform's banking institutions. Through the gold bill, the bank financing capacity of noncore enterprises is equivalent to that of core enterprises. In addition, the gold sheets can be totally or partially transferred between $1 - N$ level suppliers to suit the financing requirements of end enterprises. This mode of financing broadens the financing channels available to capital-constrained upstream and downstream enterprises. Similarly, there are innovative financial products such as "E Pay Easy" and "Credit List." For convenience, we use the name "blockchain-enabled financing mode (subsequently called B mode)" from Dong et al. [4]. By adopting the B mode, the capital-constrained subject in our study can receive gold sheets from the core business and subsequently obtain a bank loan. However, the new mode of financing is one of many alternatives available to farmers. Farmers can also employ the traditional advance payment (called A mode) and obtain direct loans from downstream firms to tackle the problem of insufficient production capital. Therefore, it is vital to investigate how farmers select a suitable mode of financing in the multitier supply chain system.

Kouvelis and Zhao contended that retailers will not pick a bank loan if effectively constructed trade credit contracts are given within the supplier early payment discount schemes [9]. In contrast, Jing and Seidmann claim that trade credit is preferable to a bank loan only when manufacturing costs are relatively low, mitigating the double marginal utility more effectively [10]. As previously noted, these studies belong to retailer financing, whereas farmers belong to suppliers. Tang et al. investigated two methods of financing suppliers: purchase order financing and buyer-direct financing [11]. They discovered that the informational advantage of the manufacturer makes buyer-direct financing the preferred method for contracting with efficient suppliers. According to Kouvelis and Xu, retailers should only offer reverse factoring to suppliers with low returns on cash investment that exceed a particular threshold [12]. However, little attention has been paid to the issue of financing the supplier in the deep-tier supply chain. Presumably, all supply chain members can increase their profits by adopting blockchain technology for finance. The value is emphasized when improvements in blockchain technology facilitate supply chain transparency and blockchain-powered smart contracts enhance the flexibility to automate loan transactions [13].

In light of those above, we provided blockchain-enabled financing to the three-tier agricultural supply chain, which includes the farmer (tier-2 supplier), the acquirer (tier-1 supplier), and the core enterprise. However, the mode is unexplored in the literature. In three-tier supply chain finance, the effect of the transmission-fee rate, which was implemented to defend the interests of tier-1 suppliers, still needs to be discovered. Comparing advance payment and blockchain-enabled financing modes, this article investigates the following concerns: (1) What are the optimal decisions for each party given the two financing modes? (2) How do the transmission-fee and interest rates influence the optimal decisions of the three-tier supply chain members? (3) How would transmission-fee and interest rates influence the parties' payoffs?

In answering the proposed research questions, we first describe the advance payment (A mode) and blockchain-enabled financing (B mode) financing operations. The decision of the financing mode by farmers is typically highly influenced by the financing cost. Consequently, we devised two distinct parameters for the two financing modes based on real-world financing scenarios and established standards from the literature. Using a comparison of operational decisions, we assess the respective values of A and B finance modes. The results demonstrate that each participant in the supply chain can select the mode of financing that best meets their demands in light of the applicable conditions. We calibrated the model utilizing the R programming language with data from the websites of the Chinese Ministry of Agriculture and Rural Development and the National Bureau of Statistics for the previous decade. We present the outcomes of numerical examples that further investigate the impact of critical parameters on the two financing methods. Therefore, the article's primary contribution is as follows:

(1) Presenting a blockchain-enabled financing mode in the three-tier agricultural supply chain.
(2) Investigating supply chain decision-making in a three-tier supply chain with a financially constrained tier-2 supplier and comparing the difference between advance payment and blockchain-enabled financing mode.

The remaining sections are organized as follows. Section 2 contains our literature review. Section 3 outlines the model structure, analyses the two financing modes, and compares the optimal decisions. Section 4 provides the numerical analysis and illustrates the influence of the crucial variables. Section 5 provides managerial insights and implications. Finally, Section 6 concludes with our results and suggestions for future research. The proofs of propositions, data sources, and model calibration results are relegated to Appendix.

2. Literature Review

2.1. Financing for Upstream Supplier. The literature related to this study is about financing for the upstream supplier. Standard financing modes include purchase order finance, advance payment, and bank loans. Ding and Wan for example, compared the two modes of advance payments from manufacturers versus a bank loan and discovered that suppliers pick just one of the two sources of financing, not both [14]. In addition, manufacturers are always eager to finance their suppliers' production with advance payments. Huang provided recommendations on the discount rate and buyer's payment timeline of the balance due for supplier disruption risk [15]. Deng et al. compared two financing modes: advance payment and a bank loan [16]. In our opinion, the advance payment also enables buyers to negotiate lower purchase prices through lower discount rates. The influence of loss aversion was of more concern to Yan et al. than the discount rate [17]. They found that the increased loss aversion of the retailer in the advance payment mode prompts it to lower the wholesale price. And greater loss aversion reduces output in the investment mode. In addition, Zhan et al. evaluated the preferences of supply chain members for advance payment against reverse factoring, taking into account the sustainability and effectiveness of the supply chain [18]. All participants favour reverse factoring, according to their findings. Moreover, Kouvelis and Zhao analysed the impact of credit ratings on supply chain operations and financial decisions while considering the financial constraints of both upstream and downstream enterprises [19]. They identified a threshold value above which the supplier offers trade credit with zero percent interest and the retailer uses exclusively trade credit. Otherwise, the supplier sets an interest rate that encourages the retailer to combine trade credit with a bank loan.

Unlike the previous articles, this article builds a three-tier agricultural supply chain. We introduced a novel blockchain-enabled financing mode to resolve this three-tier supply chain upstream capital constraints issue.

2.2. Blockchain-Enabled Financing Mode. The usage of blockchain technology in supply chain finance is growing [1, 20–23]. For example, Zheng et al. studied the applicability of smart contracts in supply chain factoring [24]. Chod et al. demonstrated that blockchain technology could provide enterprises access to advantageous financing terms at reduced signalling costs [25]. Cao et al. evaluated the role of blockchain platforms in the context of limited supplier capital [26]. They discovered that the engagement of blockchain platforms could increase the supply chain's output and total surplus. The development of a blockchain platform will always favour buyers. In most cases, suppliers can profit. Liu et al. investigated the blockchain platform finance [27]. Wang et al. focused on applying blockchain technology in trade credit [28]. However, they considered a three-tier supply chain with a capital-constrained retailer.

Only Dong et al. have explored blockchain-enabled deep-tier supply chain finance with a capital-constrained supplier, as far as we are known [4]. They demonstrated that blockchain's enhanced transparency might aid firms in making informed financing decisions for their supply chain. However, blockchain-enabled delegate financing can only raise expenditures in risk mitigation and benefit all supply chain participants when secondary suppliers are severely cash-constrained. This delegate financing allows a tier-1 supplier to borrow funds to pay a tier-2 supplier the required amount. In contrast to their delegated financing, we employ a distinct and universal mode (such as the TCL example) that enables tier-1 suppliers to split their accounts receivable and use those receivables to pay tier-2 suppliers.

2.3. Research Gap. As mentioned above, the research gap observed in the studies is related to the lack of a financing mode for tier-2 supplier financial constraints. Consequently, the blockchain-enabled finance mode has been established, and the implementation approach differs from that described by Dong et al. [4]. We share the same name with them. A lack of understanding of the impact of blockchain-enabled financing mode is a different research gap. Consequently, advance payment is also utilized in the three-tier supply chain and compared to optimal decisions and profit under the blockchain-enabled financing mode. In Table 1, research literature from the past is categorized.

3. Problem Statement

Typically, an agricultural supply chain comprises of a core enterprise and numerous upstream and downstream SMEs. This study focuses on the financing and operations of the core enterprise's tier-2 supplier. Therefore, we established an agricultural supply chain with a single core enterprise, acquirer, and capital-constrained upstream farmer. The core enterprise determines its purchase price. The acquirer then determines the acquisition price. Ultimately, the farmer chooses the planting area (e.g., 10 ha of wheat).

3.1. Notation List and Assumptions. Parameters and decision variables are defined in Table 2.

Two financing modes are considered to solve the capital constraint problem of the farmer: the advance payment (A mode) and the blockchain-enabled financing mode (B mode), denoted by superscripts A and B, respectively.

When the farmer adopts the A mode, the acquirer provides an advance payment for the farmer's production activity. As shown in Figure 1, the process between the three parties in the agricultural supply chain under the advance payment is as follows. (1) The core enterprise orders agricultural products from the acquirer at a specific price. (2) The acquirer buys agricultural products from the farmer at a predetermined price. In addition, a portion of the payment is made in advance, depending on a set discount rate to satisfy the farmer's production funding needs. (3) The farmer determines the area for planting. During harvest, it provides the acquirer with agricultural products while the acquirer pays the acquisition price. (4) The acquirer supplies the core enterprise with agricultural products. (5) The core enterprise packages and sells agricultural products to consumers after processing and packaging them.

When the farmer adopts the B mode (see Figure 2), the following sequence of events occurs between the three parties in the agricultural supply chain: (1) The core enterprise places an order with the acquirer for agricultural products at a specified price. (2) The acquirer purchases agricultural products from the farmer at a predetermined price and provides the farmer with an electronic flow certificate for a portion of the core enterprise's receivables. This certificate can be used as collateral to get a bank loan for the farmer. (3) The farmer can use that certificate as a collateral to obtain a bank loan. (4) With the assistance of a bank loan, the farmer chooses the planting area in accordance with the acquirer's buying price. The acquirer receives the goods during the harvest season. (5) The acquisition supplies the core enterprise with agricultural products. (6) The core enterprise purchases all the agricultural products from the acquirer, processes, packages them, and then sells them to the market consumers.

Therefore, the assumptions are as follows:

Table 1: Literature categorized of supply chain finance.

Reference	Supply chain	Financial constraint party	Financing mode
Kouvelis and Zhao [9]	Two tiers	Retailer	Trade credit and bank loan
Jing and Seidmann [10]	Two tiers	Retailer	Trade credit and bank loan
Tang et al. [11]	Two tiers	Supplier	Order financing and buyer-direct financing
Kouvelis and Xu [12]	Two tiers	Supplier	Reverse factoring
Ding and Wan [14]	Two tiers	Supplier	Advance payment and bank loan
Huang [15]	Two tiers	Supplier	Advance payment
Deng et al. [16]	Two tiers	Supplier	Advance payment and bank loan
Yan et al. [17]	Two tiers	Supplier	Advance payment
Ding and Wan [14]	Two tiers	Supplier	Advance payment and reverse factoring
Kouvelis and Zhao [19]	Two tiers	Supplier and retailer	Trade credit and bank loan
Liu et al. [27]	Three tiers	Retailer	Blockchain platform finance
Wang et al. [28]	Three tiers	Retailer	Trade credit using blockchain
Dong et al. [4]	Three tiers	Tier-2 supplier	Blockchain-enabled financing mode
This research	Three tiers	Tier-2 supplier	Advance payment and blockchain-enabled financing mode

Table 2: Notation list.

Variables	Description
Parameters	
p	Market price
a	Choke price
b	The price sensitivity of inverse demand function
Q	The output of agricultural products
μ	Expectation of output coefficient
q	The planting area
c_1	Unit input cost of the farmer
c	The output effort cost of the farmer
π_F	The profit of the farmer
π_S	The profit of the acquirer
π_R	The profit of the core enterprise
r_A	The discount rate about advance payment
r_E	The risk-free rate of the acquirer
r_B	Bank loan interest rate
r_1	Transmission-fee rate for the electronic certificate in B mode
Decision variables	
q	The farmer's planting area
ω	The price at which the acquirer buys the product from the farmer
ψ	The price at which the core enterprise buys the product from the acquirer

(1) In this supply chain, we assumed that both the core enterprise and the acquirer have adequate financial resources. In addition, the acquirer possesses adequate electronic flow certificates of accounts receivable (from the core enterprise). Only the farmer faces the challenge of limited capital.

(2) Since the actual output of agricultural products is subject to uncertainty, let the random output coefficient be x, i.e., the quantity of agricultural output obtained per unit of input, where the mathematical expectation is μ, e.g., 12000 kg/ha. For convenience, assume the output $Q = \mu q$, where q means the planting area.

(3) Market sales are considered to match the number of agricultural products purchased by the core firm, excluding shortage losses and unsold items' residual value. Without loss of generality, considering that the market price and sales volume of processed agricultural products obey the relationship $p = a - \mathrm{bQ}$, where $a\,(>0)$ denotes the choke price; consumers will not buy the commodity when the market price exceeds the choke price. The parameter b indicates the price sensitivity of the inverse demand function.

(4) The farmer decides the planting area based on the purchase price and financing cost, where the quadratic production cost function $C(q) = c_1 q + cq^2$ is commonly used to describe the diseconomies of scale [26, 29, 30], c_1 representing the input cost coefficient, $c_1 q$ representing the cost of cultivating arable land for inputs such as seeds, fertilizers, and pesticides, and c reflects the coefficient of output effort cost. A bigger output effort input indicates inefficiency. To simplify the computation without compromising its generality, let $c_1 = 0$, $c > 0$.

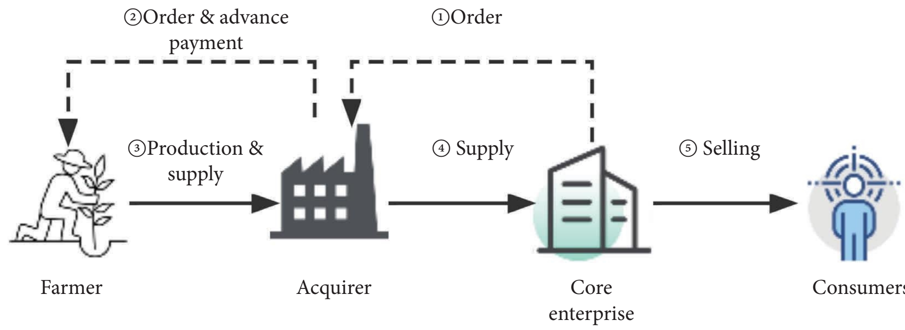

Figure 1: A mode process.

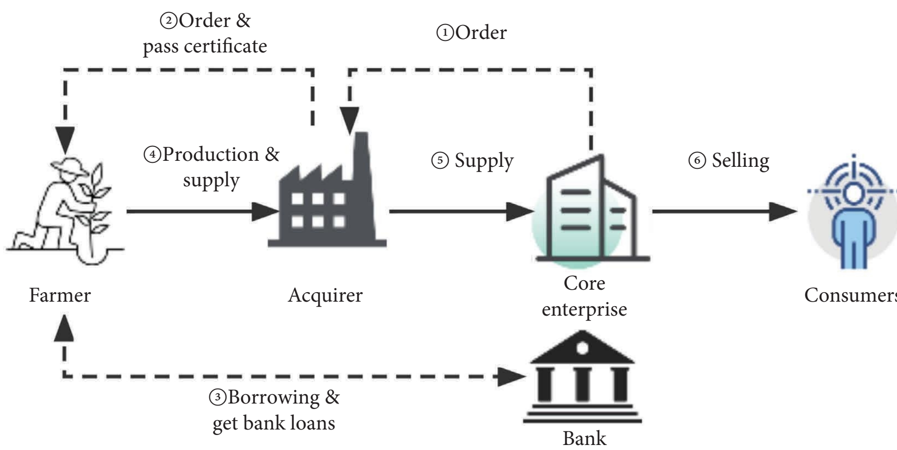

Figure 2: B mode process.

(5) The profit of each party is represented by π_i, $i = F, S, R$, and the subscripts F, S, and R, respectively, represent the farmer, the acquirer, and the core enterprise.

(6) We assume that the acquirer's discount rate for advance payment is r_A and the risk-free rate is r_E, which can be viewed as the acquirer's bank financing capability and $r_A > r_E$.

(7) We assume that the interest rate on the farmer's bank loan in B mode is r_B. It can be considered the farmer's bank financing capacity under the B mode. The farmer needs to pay the fees to the acquirer at transmission-fee rate r_1. Assuming $r_B + r_1 < r_A$, otherwise it would not be profitable for the farmer to adopt the B mode.

(8) We also assumed that the cost of supply chain investment in blockchain technology is zero, and we disregarded the cost of using the blockchain platform. We examined the matter of the farmer's choice of financing mode in terms of the loan cost required to execute various financing modes. Because on the one hand, local government departments in pilot zones typically finance new technology inputs to decrease or even cover the cost of digitization. On the other hand, our research focuses on the costs and benefits that result from applying the financing mode. Considering the fact that technological inputs will become sunk costs over time, eliminating sunk costs can better account for the essential differences between the two financing modes by excluding unnecessary impacts.

3.2. Solution Approaches

3.2.1. Advance Payment (A Mode). Advance payment is the traditional mode of financing that helps reduce the farmer's financial constraints. At this time, each member's profit functions are as follows:

$$\begin{aligned}\pi_F^A &= \omega Q - cq^2(1 + r_A),\\ \pi_S^A &= (\psi - \omega)Q + cq^2(r_A - r_E),\\ \pi_R^A &= (p - \psi)Q.\end{aligned} \tag{1}$$

The decision function of the farmer is as follows:

$$\max \pi_F^A = \max\left(\omega Q - cq^2(1 + r_A)\right). \tag{2}$$

Solving the above equation, the optimal planting area for production can be determined as follows:

$$q = \frac{\mu\omega}{2c(1 + r_A)}. \tag{3}$$

The acquirer's decision function is as follows:

$$\max \pi_S^A(q) = \max\left((\psi - \omega)Q - cq^2(r_A - r_E)\right). \tag{4}$$

Solving the above equation, we can obtain the optimal purchase price as follows:

$$\omega = \frac{(1 + r_A)\psi}{2 + r_A + r_E}. \tag{5}$$

Substituting the values of q and ω into the core firm profit function, the core firm optimal decision function is as follows:

$$\max \pi_R^A (q, \omega) = \max ((p - \psi)Q). \tag{6}$$

Solving the above equation, we can obtain the optimal purchase price as follows:

$$\psi^* = \frac{ac(2 + r_A + r_E)}{2c(2 + r_A + r_E) + b\mu^2}. \tag{7}$$

The equilibrium solution in the A mode is shown as follows:

$$q_A^* = \frac{a\mu}{4c(2 + r_A + r_E) + 2b\mu^2}, \tag{8}$$

$$\omega_A^* = \frac{ac(1 + r_A)}{2c(2 + r_A + r_E) + b\mu^2}, \tag{9}$$

$$\psi_A^* = \frac{ac(2 + r_A + r_E)}{2c(2 + r_A + r_E) + b\mu^2}, \tag{10}$$

$$\pi_F^{A*} = \frac{a^2\mu^2(1 + r_A)c}{4\left(2c(2 + r_A + r_E) + b\mu^2\right)^2}, \tag{11}$$

$$\pi_S^{A*} = \frac{a^2\mu^2(2 + r_A + r_E)c}{4\left(2c(2 + r_A + r_E) + b\mu^2\right)^2}, \tag{12}$$

$$\pi_R^{A*} = \frac{a^2\mu^2}{4\left(2c(2 + r_A + r_E) + b\mu^2\right)}. \tag{13}$$

3.2.2. Blockchain-Enabled Financing Mode (B Mode). The blockchain-enabled financing mode has been used to address the financial constraints of the deep-tier supply chain [4, 27]. At this point, the profit function of each member is as follows:

$$\begin{aligned} \pi_F^B &= \omega Q - cq^2(1 + r_B + r_1), \\ \pi_S^B &= (\psi - \omega)Q + cq^2 r_1, \\ \pi_R^B &= (p - \psi)Q. \end{aligned} \tag{14}$$

The farmer's decision function is shown as follows:

$$\max \pi_F^B = \max\left(\omega Q - cq^2(1 + r_B + r_1)\right). \tag{15}$$

Solving equation (15), we can obtain the optimal area of arable land for production as follows:

$$q = \frac{\mu\omega}{2c(1 + r_B + r_1)}. \tag{16}$$

Substituting q into the acquirer's profit function, the acquirer's optimal decision function is as follows:

$$\max \pi_S^B(q) = \max\left((\psi - \omega)Q + cq^2 r_1\right). \tag{17}$$

Solving the above equation, we can obtain the optimal purchase price as follows:

$$\omega = \frac{\psi(1 + r_B + r_1)}{2(1 + r_B) + r_1}. \tag{18}$$

Substituting the values of q and ω into the core firm profit function, the core firm optimal decision function is as follows:

$$\max \pi_R^B (q, \omega) = \max ((p - \psi)Q). \tag{19}$$

Solving equation (19), we can obtain the optimal purchase price as follows:

$$\psi^* = \frac{ac(2(1 + r_B) + r_1)}{4c(1 + r_B) + 2cr_1 + b\mu^2}. \tag{20}$$

The equilibrium solution in the B mode is shown as follows:

$$q_B^* = \frac{a\mu}{2\left(4c(1 + r_B) + 2cr_1 + b\mu^2\right)}, \tag{21}$$

$$\omega_B^* = \frac{ac(1 + r_B + r_1)}{4c(1 + r_B) + 2cr_1 + b\mu^2}, \tag{22}$$

$$\psi_B^* = \frac{ac(2(1 + r_B) + r_1)}{4c(1 + r_B) + 2cr_1 + b\mu^2}, \tag{23}$$

$$\pi_F^{B*} = \frac{a^2\mu^2 c(1 + r_B + r_1)}{4\left(4c(1 + r_B) + 2cr_1 + b\mu^2\right)^2}, \tag{24}$$

$$\pi_S^{B*} = \frac{a^2\mu^2 c(2(1 + r_B) + r_1)}{4\left(4c(1 + r_B) + 2cr_1 + b\mu^2\right)^2}, \tag{25}$$

$$\pi_R^{B*} = \frac{a^2\mu^2}{4\left(4c(1 + r_B) + 2cr_1 + b\mu^2\right)}. \tag{26}$$

3.3. Comparison of Advance Payment and Blockchain-Enabled Financing Mode

3.3.1. Comparison of Purchase Price. We derived the following propositions by comparing the acquirer and the core enterprise purchase price between advance payment and blockchain-enabled financing modes.

Proposition 1. *(1) When $r_B < r_E$, there is a threshold value $\hat{r}_0$. If $r_1 > \hat{r}_0$, we have $\omega_B^* > \omega_A^*$. If $r_1 < \hat{r}_0$, we have $\omega_B^* < \omega_A^*$. If $r_1 = \hat{r}_0$, we have $\omega_B^* = \omega_A^*$. (2) When $r_B \geq r_E$, $\omega_B^* < \omega_A^*$ constantly holds. The expression of $\hat{r}_0$ is as follows:*

$$\widehat{r}_0 = \frac{(r_A - r_B)b\mu^2 + 2c(r_A - r_E)(1 + r_B)}{b\mu^2 + 2c + 2cr_E}. \quad (27)$$

See Appendix A for a detailed description of the proof procedure and the proofs of the following propositions.

Proposition 1 states that: (1) when the acquirer offers a higher transmission-fee rate, the acquirer also increases the acquisition price. The higher the transmission-fee rate, the greater the acquirer's transmission revenue. The acquirer must raise the acquisition price to encourage the farmer to cultivate a larger area. (2) If the farmer's bank financing ability remains insufficient after adopting B mode (i.e., $r_B \geq r_E$), the purchase price of B mode is always lower than that of A mode, regardless of the transmission-fee rate. That is because the transmission revenue of the acquirer in B mode is always lower than the interest revenue in A mode (i.e., $cq^2(r_A - r_E) > cq^2 r_1$) when the farmer's area under cultivation is given. The acquirer in B mode will seek a reduced acquisition price to offset this income loss.

Proposition 2. *(1) When $r_B \leq r_E$, $\psi_B^* < \psi_A^*$ constantly holds. (2) When $r_B > r_E$, there is a threshold value $\widehat{r}_1$. If $r_1 > \widehat{r}_1$, we have $\psi_B^* > \psi_A^*$. If $r_1 < \widehat{r}_1$, we have $\psi_B^* < \psi_A^*$. If $r_1 = \widehat{r}_1$, we have $\psi_B^* = \psi_A^*$. The expression of $\widehat{r}_1$ is as follows.*

$$\widehat{r}_1 = r_A + r_E - 2r_B. \quad (28)$$

Proposition 2 shows that (1) the purchase price of core enterprises under B mode is less if the farmer's bank financing ability is greater after adopting B mode (i.e., $r_B \leq r_E$) because the market for agricultural products is characterized by great volume and low prices (see Proposition 3 (1)). To increase revenue, the core enterprise will seek to reduce the buying price. (2) If the farmer's bank financing ability remains insufficient after adopting the B mode (i.e., $r_B > r_E$), the core enterprise in the B mode will demand a lower purchase price only if the acquirer offers a lower transmission-fee rate. For the same reason as above, see Proposition 3 (2) for details.

3.3.2. Comparison of Expected Production Volumes. We derived the following proposition by comparing the farmer's expected production volumes between advance payment and blockchain-enabled finance modes.

Proposition 3. *(1) When $r_B \leq r_E$, $Q_B^* > Q_A^*$ constantly holds. (2) When $r_B > r_E$, there is a threshold value $\widehat{r}_2$. If $r_1 > \widehat{r}_2$, we have $Q_B^* < Q_A^*$. If $r_1 < \widehat{r}_2$, we have $Q_B^* > Q_A^*$. If $r_1 = \widehat{r}_2$, we have $Q_B^* = Q_A^*$. The expression of $\widehat{r}_2$ is as follows:*

$$\widehat{r}_2 = \widehat{r}_1 = r_A + r_E - 2r_B. \quad (29)$$

Proposition 3 states that (1) if the farmer's bank financing ability is greater in the B mode (i.e., $r_B \leq r_E$), the farmer will always decide to plant more crops in the B mode because the farmer's production costs are lower in B mode. And even if the transmission-fee rate is high, the acquirer will encourage the farmer to increase the planting area by raising the purchase price. (2) If the farmer's bank financing ability remains insufficient after adopting B mode (i.e., $r_B \geq r_E$), the planting area under B mode is smaller than under A mode when the transmission-fee rate is high. Because the acquirer's purchase price is also lower at this time, the farmer cannot be encouraged to increase the planting area (see Proposition 1 for details).

3.3.3. Comparison of Profit. We obtained the following propositions by comparing the profit of the farmer, the acquirer, and the core enterprise between the advance payment and blockchain-enabled financing modes.

Proposition 4. *(1) When $r_B > (r_A + r_E - r_1)/2$, $\pi_F^{B*} < \pi_F^{A*}$ constantly holds. (2) When $r_B < (r_A + r_E - r_1)/2$, there are two threshold values $\widehat{r}_3$ and $\widehat{r}_4$. If $\widehat{r}_3 < r_1 < \widehat{r}_4$, we have $\pi_F^{B*} > \pi_F^{A*}$.*

The expressions of $\widehat{r}_3$ and $\widehat{r}_4$ are as follows:

$$\widehat{r}_3 = \frac{M^2 - 4(1 + r_A)cN - \Delta}{8(1 + r_A)c^2}, \quad \widehat{r}_4 = \frac{M^2 - 4(1 + r_A)cN + \Delta}{8(1 + r_A)c^2}, \quad (30)$$

in which $M = b\mu^2 + 2c(2 + r_A + r_E)$,

$$N = b\mu^2 + 4c(1 + r_B), \text{and} \quad \Delta = M\sqrt{M^2 - 8c(1 + r_A)(b\mu^2 + 2c(1 + r_B))}. \quad (31)$$

Proposition 4 shows that (1) if the farmer's bank financing ability remains insufficient, the farmer will always choose A mode to maximize profits, regardless of the transmission-fee rate. In contrast, after selecting B mode, the acquirer's purchase price is lower, resulting in a smaller planting area for the farmer, which is not favourable to increasing the farmer's profit. (2) It shows that the transmission-fee rate only increases the farmer's profit within a certain range when B mode is selected. A low transmission-fee rate does not increase the farmer's profit because the acquirer will set a lower buying price when the rate is low. A costly transmission fee will force the farmer to undertake high capital costs, hence lowering the farmer's profit.

Proposition 5. *If $r_1 < \widehat{r}_5$, we have $\pi_S^{B*} > \pi_S^{A*}$. The expression of $\widehat{r}_5$ is as follows:*

$$\widehat{r}_5 = r_A + r_E - 2r_B = \widehat{r}_2 = \widehat{r}_1. \quad (32)$$

Proposition 6. *If $r_1 < \widehat{r}_6$, we have $\pi_R^{B*} > \pi_R^{A*}$. The expression of $\widehat{r}_6$ is as follows:*

$$\widehat{r}_6 = r_A + r_E - 2r_B = \widehat{r}_5 = \widehat{r}_2 = \widehat{r}_1. \quad (33)$$

When the farmer selects the B mode, and the acquirer offers a low transmission-fee rate, the acquirer and the core firm can increase their earnings, as illustrated by Propositions 5 and 6. The reason is that a low transmission-fee rate encourages the farmer to increase the planting area, which will increase the profits of the downstream firms.

Corollary 1. *If $\hat{r}_3 < r_1 < \hat{r}_6$, the farmer, acquirer, and core enterprise can achieve a win-win situation for all three parties.*

The inference result implies that, when selecting B mode, the acquirer can set a suitable transmission-fee rate to ensure that all participants of the supply chain benefit. Not only does this raise their profits, but it also strengthens the cooperative relationship amongst supply chain partners.

3.4. Results and Discussion. In order to tackle the financial constraint problem of the farmer in a three-tier agricultural supply chain, we first created game models of two financing modes based on the relevant assumptions and variables. Next, the optimal decisions under two financing options, including the farmer's planting area, the acquirer's purchase price, and the core enterprise's purchase price, are produced using the inverse induction method. Finally, we evaluated the differences in optimal decisions and profits between the two financing modes from a theoretical perspective. On the one hand, the relationship between r_B and r_E directly affects whether the two financing mode decisions are equivalent. On the other hand, the analysis also reveals that the transmission-fee rate r_1 is somewhat moderating since it can further reduce or increase the farmer's actual financing cost. The good range of r_1 can result in a win-win situation for all three partners in the three-tier supply chain, especially when comparing profits. Although studies have been undertaken to illustrate the usefulness of the new method [4, 27], our results show that there are constraints in motivating the supply chain to accept the new financing mode. Sometimes, the traditional financing mode may be better instead. These analyses also lay the foundation for the subsequent numerical analysis.

4. Numerical Analysis

4.1. Model Calibration. This section focuses on the effects of key parameters on the three-tier agricultural supply chain. To improve the validity and accuracy of simulation findings, we obtained data from the websites of the Chinese Ministry of Agriculture and Rural Development and the National Bureau of Statistics to calibrate models. We used the national average yield and acreage statistics for soybean and wheat from 2011 to 2019 to calculate their median output coefficients: 3626.913 kg/ha and 10785.239 kg/ha, respectively.

Similar to Alizamir et al. [31], we constructed the adjusted market price using the consumer price index for residential prices to eliminate the effect of inflation. And we also obtained the adjusted agricultural output data with the number of townships in the country to eliminate the substantial disparities in scale between the data sets. Furthermore, using adjusted market prices as the dependent variable and adjusted output as the independent variable, we estimated the values of a, b by a linear regression equation. Regarding the quadratic term coefficients, we gathered national data on multiple expenses of wheat and soybeans for 2016–2018, including explicit and implicit costs, with reference to Alizamir's study. We substituted the difficult-to-record effort costs in the quadratic production cost function with implicit costs (such as discounted rent for self-camping and discounted wage for household labour). To get the value of the quadratic coefficient, let the overall cost equal the sum of the quadratic costs. We also used three years of data to get the average quadratic term coefficients as simulation parameters. Table 3 demonstrates the specific estimation results. Appendix B provides more information on the data. Given the greater fit and significance found for the soybean data, which can more accurately represent the actual scenario, the estimated results for the soybean data were used as the simulation parameters.

4.2. The Impact of Important Parameters on the Supply Chain

4.2.1. Advance Payment. In the context of the advance payment, the market price is $p_A = 7.343 - 0.0316q_A^*$. Considering the reality, assign the parameters as follows: $r_A \in [0.04, 0.12]$ and $r_E \in [0, 0.06]$. In Table 4, we set $r_E = 0.04$ and show the impact of r_A changes on each supply chain member's decision variables and profits.

Based on Table 4, the result shows that as r_A increases, the farmer's planting area, the acquirer, and core enterprise profits will decrease. However, the farmer's profit, the acquirer, and core enterprise purchase prices will increase.

Similarly, we set $r_A = 0.12$ and show impact of r_E changes in Table 5. The result shows that as r_E increases, only the core enterprise purchase price will increase and other decision variables with all supply chain members profits will decrease.

4.2.2. Blockchain-Enabled Financing Mode. In the context of the blockchain-enabled financing mode, the market price is $p_B = 7.343 - 0.0316q_B^*$. Considering the reality, assign the parameters as follows: $r_1 \in [0, 0.08]$ and $r_B \in [0, 0.10]$. In Table 6, we set $r_B = 0.10$ and show impact of r_1 changes on each supply chain member's decision variables and profits.

Based on Table 6, the result shows that as r_1 increases, the farmer's planting area, the acquirer, and core enterprise profits will decrease. However, the farmer's profit, the acquirer, and core enterprise purchase prices will increase.

Then, we set $r_1 = 0.02$ and show impact of r_B changes in Table 7. The result shows that as r_B increases, the farmer's planting area and all supply chain members' profits will decrease. However, the acquirer and core enterprise purchase prices will increase.

4.3. The Impact of Critical Parameters on Profit Gap between Two Financing Modes. The sensitivity analysis results of the critical variables have been shown previously. The impact of the transmission-fee rate and interest rate involved in B mode on the profit gap of both financing modes will be examined next. We assumed that relevant parameters are $r_E = 0.06$ and $r_A = 0.12$ based on China's benchmark interest rate and practical applications. The implications of a farmer's bank financing ability on the performance of

Table 3: Parameter estimation results.

Parameters	Soybean	Wheat
a	7.343	2.136
b	0.000008701	0.000000005236
c	243.723	119.2888

Table 4: The impact of r_A on decision variables and supply chain profits.

r_A	q_A^*	ω_A^*	ψ_A^*	π_F^{A*}	π_S^{A*}	π_R^{A*}
0.04	11.8015	1.6495	3.2991	35303	70605	157150
0.08	11.6011	1.6839	3.3054	35426	69539	154480
0.12	11.4073	1.7171	3.3115	35521	68504	151900

Table 5: The impact of r_E on decision variables and supply chain profits.

r_E	q_A^*	ω_A^*	ψ_A^*	π_F^{A*}	π_S^{A*}	π_R^{A*}
0.00	11.6011	1.7462	3.3054	36738	69539	154480
0.03	11.4551	1.7243	3.3100	35819	68760	152540
0.06	11.3128	1.7029	3.3145	34935	67998	150640

Table 6: The impact of r_1 on decision variables and supply chain profits.

r_1	q_B^*	ω_B^*	ψ_B^*	π_F^{B*}	π_S^{B*}	π_R^{B*}
0.00	11.2199	1.6587	3.3174	33749	67499	149410
0.04	11.0386	1.6912	3.3231	33855	66523	146990
0.08	10.8630	1.7227	3.3287	33937	65574	144650

Table 7: The impact of r_B on decision variables and supply chain profits.

r_B	q_B^*	ω_B^*	ψ_B^*	π_F^{B*}	π_S^{B*}	π_R^{B*}
0.03	11.8015	1.6654	3.2991	35642	70605	157150
0.06	11.5034	1.6697	3.3085	34831	69018	153180
0.10	11.1285	1.6751	3.3203	33805	67007	148190

agricultural supply chain members in various scenarios are examined separately in the following sections. (I) Let $r_B = 0.10$ and $r_B > r_E$, i.e., the bank financing capacity of the farmer remains weak. (II) Let $r_B = 0.06$ and $r_B = r_E$, i.e., the farmer has the same bank financing ability as the acquirer. (III) Let $r_B = 0.03$ and $r_B < r_E$, i.e., the farmer can leverage the role of core enterprise to obtain bank loans at a lower interest rate in the three-tier supply chain.

4.3.1. The Farmer's Profit Gap. Figure 3 illustrates, for a given transmission-fee rate, the profit gap of the farmer under the two financing modes with varying bank financing capacities.

When the farmer's bank financing ability is less than the acquirer's, the farmer will not apply the B mode. When the farmer's bank financing ability is more than or equal to the acquirer's, the farmer will only select B mode if the transmission-fee rate falls within a certain range, which is consistent with Proposition 4, and Figures 4 and 5 demonstrate similar outcomes.

Moreover, when the bank loan interest rate remains constant, the profitability of the farmer under B mode grows as the transmission-fee rate rises. In other words, the higher the transmission-fee rate, the greater the farmer's motivation to finance through the B mode. It implies that increasing the transmission-fee rate is an effective method to encourage B mode and enhance the willingness of upstream enterprises in the agricultural supply chain to participate.

4.3.2. The Acquirer's Profit Gap. As shown in Figure 4, when the farmer's bank financing ability is constant, the profitability of the acquirer under the B mode decreases as the transmission-fee rate increases.

We also found that when the profitability of the acquirer is constant, the acquirer will offer a higher transmission-fee rate to the farmer as their bank financing ability increases. Overall, the profitability of the acquirer under the B mode always decreases with the transmission-fee rate increase. At this point, the farmer pays a higher capital cost but receives a higher purchase price. Profits for the acquirer are generated by the transmission fee and the selling of agricultural products. Therefore, when the sales revenue surrendered by the acquirer is not enough to cover the increased revenue from the transmission fee, it will decrease the total profit.

4.3.3. The Core Enterprise's Profit Gap. As seen from Figure 5, when the farmer's ability to get bank loans stays unchanged, the transmission-fee rate will reduce the profitability of the core enterprise under the B mode.

The increasing transmission-fee rate will decrease the profitability of the core enterprises. The reason is that the acquirer will seek a higher purchase price from the core enterprise. In summary, from the perspective of the agricultural supply chain, the acquirer can transfer the revenue of the downstream core enterprise to the upstream farmer by increasing the transmission-fee rate under B mode. In other words, the B mode can enable the upstream firm to enhance its revenue by reducing the core enterprise's power advantage as the game leader.

In addition, both Figures 4 and 5 demonstrate that while the transmission-fee rate is constant, the profitability of the acquirer and the core enterprise increases as the bank loan interest rate of the farmer decreases. Therefore, they are incentivized to help the farmer negotiate for a lower bank interest rate. However, decreasing the transmission-fee rate has good or negative implications for the profitability of all agricultural supply chain participants. It can be inferred that the alternative of supporting the farmer to lower the interest rate will be more effective if government departments encourage blockchain technology by subsidizing B mode because it can assist to reduce conflicts of interest among the members of the three-tier supply chain and increase the profitability of all supply chain participants.

5. Managerial Insights and Practical Implications

The financing mode helps to solve the issue of SMEs' financial constraints. When faced with a choice, the farmer anticipates that the selected financing mode will have minimal expenses

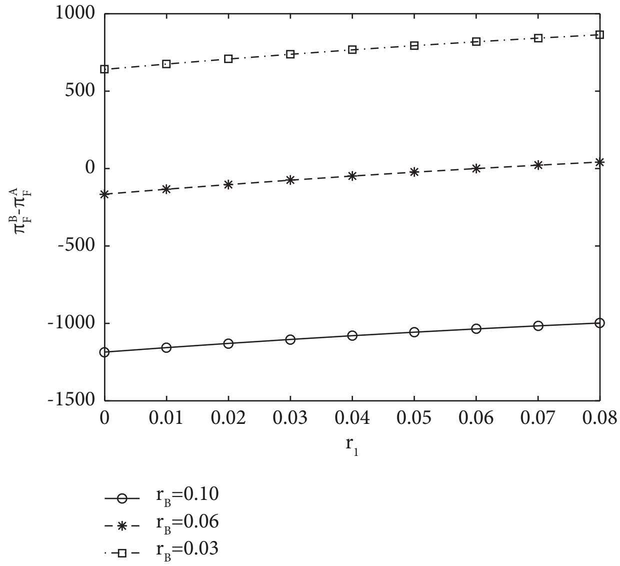

Figure 3: Change of the farmer's profit under different financing modes.

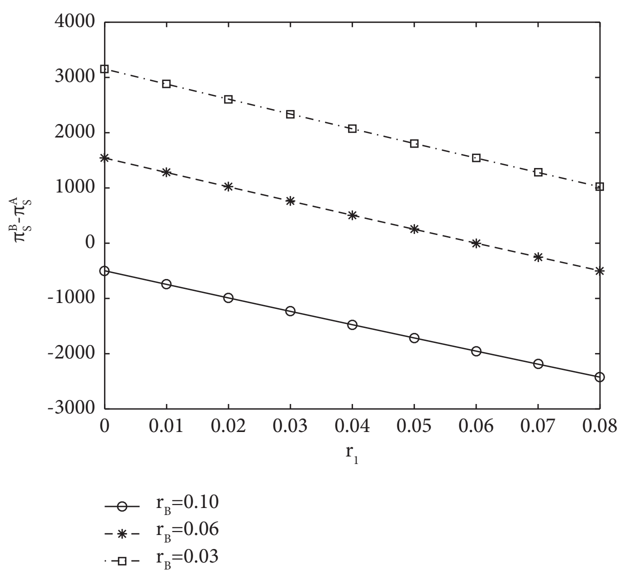

Figure 4: Change of acquirer's profit under different financing modes.

and generate high profits. Considering that financing costs can be immediately observed in the form of interest rate or transmission-fee rate, it is likely that the farmer will miss the financing mode that may bring higher profits between advance payment and blockchain-enabled financing mode. A farmer, for instance, may select the advance payment and reject the blockchain-enabled financing mode due to the high transmission-fee rate. According to our findings, however, a high transmission-fee rate also drives the acquirer to increase their buy price and, consequently, the farmer's profits. Therefore, when promoting blockchain-enabled financing mode, companies or the government must attract attention to this issue so that farmers are aware of the potential profits and select the most suitable financing mode.

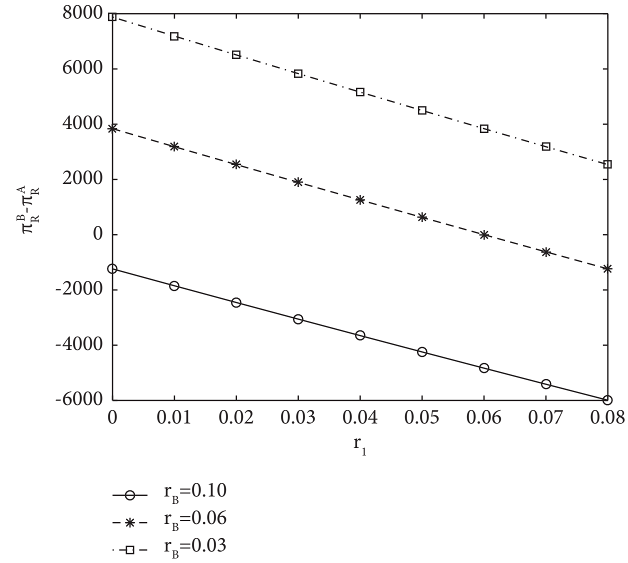

Figure 5: Change of core enterprise's profit under different financing modes.

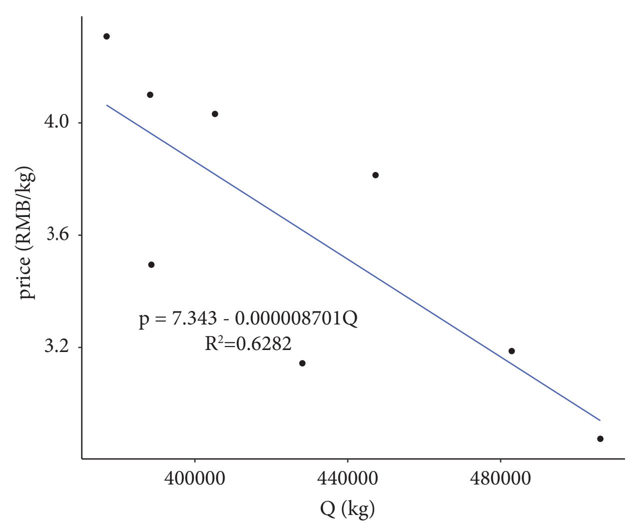

Figure 6: Scatter plot and fitted curve of soybean price vs. production.

For governments, supporting the acceptance of new financing modes can accelerate the development of new technologies. However, policies must be carefully designed to establish which of the three tiers of the supply chain is the most effective subsidy target. In the early stages of new technology development, governments frequently provide subsidized fees to encourage firms to adopt new technologies. However, it is preferable to help farmers rather than other companies. According to our findings, lowering the bank interest rate in the blockchain-enabled financing mode has a positive influence on all three tiers of the supply chain. Lowering the transmission-fee rate will negatively impact some members. It indicates that companies implementing new technologies and financing modes must be effectively informed and guided to completely comprehend the distinctions between the two financing modes and reach a win-win situation.

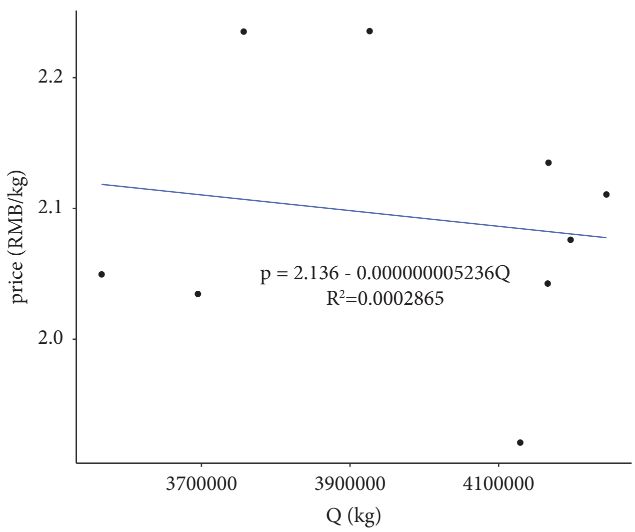

Figure 7: Scatter plot and fitted curve of wheat price vs. production.

6. Conclusions and Outlook

The use of supply chain finance to solve the issue of upstream financial constraints for core firms has been a widely discussed topic. The recent development of blockchain technology presents a further potential for addressing the three-tier funding constraint in the supply chain. This article compares and analyses two financing modes for addressing the upstream financing constraint problem in a three-tier supply chain: the traditional advance payment and the blockchain-enabled financing mode. The latter does not seem to dominate fully, but the appropriate transmission-fee rate setting does lead to more profits for all participants in the three-tier supply chain.

Specifically, we constructed a three-tier agricultural supply chain that included the capital-constrained farmer, the acquirer, and the core enterprise. The decisions and profits of the three members under the advance payment and the blockchain-enabled financing mode are investigated, then the two financing modes are compared. The findings indicate as follows:

(1) The premise underlying the farmer's choice of the blockchain-enabled financing mode is that their bank financing ability is stronger under this mode. Because supply chain finance will play the role of core enterprises, it lowers the financing rate and enhances the financing ability of SMEs. The blockchain-enabled financing mode can extend the advantages of supply chain finance to remote farmers in the three-tier supply chain and improve their bank financing ability, so the premise holds.

(2) Other members have also influenced the introduction of the blockchain-enabled financing mode in the agricultural supply chain. The transmission-fee rate should fall within a specific range to establish a win-win situation for all three participants. Specifically, a transmission-fee rate that is too low will decrease the farmer's profitability. At the same time, a transmission-fee rate that is too high will reduce the profitability of the acquirer and core enterprise.

(3) To promote the application of blockchain technology by the blockchain-enabled financing mode, government departments should provide targeted policy subsidies to the farmer rather than other members. It will further reduce the farmer's bank loan interest rate and improve their financing ability.

For future deep-tier supply chain finance research, some suggestions are presented. First, our work explores the supply chain of a single farmer. Future research can be extended to the supply chain model that includes multiple farmers [31] to address other open questions. Second, demand uncertainty and the risk of bankruptcy [9, 14] for the farmer have not been considered. It will be interesting to deepen the mathematics to explore differences in financing modes in terms of robustness [32–36], stochasticity [37], etc. Finally, this article assumes that the acquirer can pass the electronic flow certificate to the farmer in the blockchain-enabled financing mode. Various supply chain finance tools, such as guarantee and reverse factoring [12], could be considered in future research.

Appendix

A. Proof Process of Propositions

Proof 1. According to equations (9) and (20), we have the following equation:

$$\omega_B^* - \omega_A^* = \frac{ac}{\mathbb{Z}}\left[r_1\left(b\mu^2 + 2c + 2cr_E\right) - \left(r_A - r_B\right)b\mu^2 - 2c\left(r_A - r_E\right)\left(1 + r_B\right)\right], \quad (A.1)$$

Here $\mathbb{Z} = [b\mu^2 + 4c(1 + r_B) + 2cr_1] * \{2c[2(1 + r_A) - (r_A - r_E)] + b\mu^2\}$.

Let $\omega_B^* - \omega_A^* = 0$, we can obtain the following equation:

$$\hat{r}_0 = \frac{(r_A - r_B)b\mu^2 + 2c(r_A - r_E)(1 + r_B)}{b\mu^2 + 2c + 2cr_E}. \quad (A.2)$$

Based on the assumption $r_B + r_1 < r_A$, we have $(r_A - r_B)b\mu^2 > r_1 b\mu^2$. Therefore, we can obtain the following equation:

(1) When $r_B < r_E$, if $r_1 > \hat{r}_0$, we have the following equation:

$$r_1\left(b\mu^2+2c+2cr_E\right)-\left(r_A-r_B\right)b\mu^2-2c\left(r_A-r_E\right)\left(1+r_B\right)>0, \tag{A.3}$$

i.e., $\omega_B^*>\omega_A^*$. Similarly, if $r_1<\widehat{r}_0$, $\omega_B^*<\omega_A^*$. If $r_1=\widehat{r}_0$, $\omega_B^*=\omega_A^*$.

(2) When $r_B\geq r_E$, we have $r_A-r_E\geq r_A-r_B>r_1$ and $1+r_E\leq 1+r_B$, i.e.,

$$r_1\left(1+r_E\right)<\left(r_A-r_E\right)\left(1+r_B\right), \tag{A.4}$$

So, $r_1\left(b\mu^2+2c+2cr_E\right)-\left(r_A-r_B\right)b\mu^2-2c\left(r_A-r_E\right)\left(1+r_B\right)<0$ holds, i.e., $\omega_B^*<\omega_A^*$ holds. □

Proof 2. According to equations (10) and (21), we have the following equation:

$$\psi_B^*-\psi_A^*=\frac{acb\mu^2\left[r_1-\left(r_A+r_E-2r_B\right)\right]}{\mathbb{Z}}. \tag{A.5}$$

Let $\psi_B^*-\psi_A^*=0$, we can obtain $\widehat{r}_1=r_A+r_E-2r_B$.

Based on the assumption $r_B+r_1<r_A$, we have the following:

(1) When $r_B\leq r_E$, $r_1-\left(r_A+r_E-2r_B\right)=r_1-\left(r_A-r_B+r_E-r_B\right)<0$ holds, i.e., $\psi_B^*<\psi_A^*$ holds.

(2) When $r_B>r_E$, if $r_1>\widehat{r}_1$, we have $r_1-\left(r_A+r_E-2r_B\right)>0$, i.e., $\psi_B^*>\psi_A^*$. Similarly, if $r_1<\widehat{r}_1$, $\psi_B^*<\psi_A^*$. If $r_1=\widehat{r}_1$, $\psi_B^*=\psi_A^*$. □

Proof 3. According to equations (8) and (19) and assumption (3), we have the following equation:

$$Q_B^*-Q_A^*=\frac{ac\mu\left(r_A+r_E-2r_B-r_1\right)}{\mathbb{Z}}. \tag{A.6}$$

Let $Q_B^*-Q_A^*=0$, we can obtain $\widehat{r}_2=r_A+r_E-2r_B=\widehat{r}_1$. Based on the assumption $r_B+r_1<r_A$, then we have the following:

(1) When $r_B\leq r_E$, $r_A+r_E-2r_B-r_1=r_A-r_B+r_E-r_B-r_1>0$ holds, i.e., $Q_B^*>Q_A^*$ holds.

(2) When $r_B>r_E$, if $r_1>\widehat{r}_2$, we have $r_A+r_E-2r_B-r_1<0$, i.e., $Q_B^*<Q_A^*$. Similarly, if $r_1<\widehat{r}_2$, $Q_B^*>Q_A^*$. If $r_1=\widehat{r}_2$, $Q_B^*=Q_A^*$. □

Proof 4. According to equations (11) and (22), we have the following equation:

$$\pi_F^{B*}-\pi_F^{A*}=\frac{a^2\mu^2c}{4\left(N+2cr_1\right)^2M^2}\left[\left(1+r_B+r_1\right)M^2-\left(1+r_A\right)\left(N+2cr_1\right)^2\right]. \tag{A.7}$$

Let $\pi_F^{B*}-\pi_F^{A*}=0$, we can obtain $\widehat{r}_3$ and $\widehat{r}_4$. □

Proof 5. According to equations (12) and (23), we have the following equation:

$$\pi_S^{B*}-\pi_S^{A*}=\frac{a^2\mu^2c}{4\left(N+2cr_1\right)^2M^2}\left\{\left[2\left(1+r_B\right)+r_1\right]M^2-\left(2+r_A+r_E\right)\left(N+2cr_1\right)^2\right\}. \tag{A.8}$$

Let $\pi_S^{B*}-\pi_S^{A*}=0$, we can obtain $\widehat{r}_5$. □

Proof 6. According to equations (13) and (24), we have the following equation:

$$\pi_R^{B*}-\pi_R^{A*}=\frac{2a^2\mu^2c\left(r_A+r_E-2r_B-r_1\right)}{4\mathbb{Z}}. \tag{A.9}$$

Let $\pi_R^{B*}-\pi_R^{A*}=0$, we can obtain $\widehat{r}_6$. □

B. Scatter Plots and Fitting Curves of Different Crop Price and Production

Here, we provided scatter plots and fitted curves on market prices versus production for the last nine years for both crops (Figures 6 and 7). Raw price, production, and cost data are from the Chinese Ministry of Agriculture and Rural Affairs website (https://zdscxx.moa.gov.cn:8080/nyb/pc/index.jsp). Consumer price index data are from the website of the National Bureau of Statistics (https://www.stats.gov.cn/).

Data Availability

We have provided scatter plots and fitted curves on market prices versus production for both crops using data from 2011–2019. Raw price, production, and cost data are from the Chinese Ministry of Agriculture and Rural Affairs website (https://zdscxx.moa.gov.cn:8080/nyb/pc/index.jsp). Consumer price index data are from the website of the National Bureau of Statistics (https://www.stats.gov.cn/).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A New Mathematical Model for Economic Ordering with Preventive Maintenance and Reworking in a Supply Chain

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Cost reduction in production systems is one of the main concerns of most manufacturing industries. Achieving this goal requires the effective use of resources. Nowadays, due to the competitiveness of production and the need to reduce costs and deliver goods on time, equipment availability and prevention of unexpected stops are particularly important in industrial units. In recent years, equipment, machinery, and human resources have been the foundations of any organization. On the other hand, to increase the productivity and efficiency of providing services and achieve global standards, special attention should be paid to increase the efficiency of machinery and reducing downtime costs. This research conducted a mathematical formulation to find the best possible solution for the economic production quantity and inventory ordering by considering preventive maintenance. In this model, the success of organizations in providing services and increasing the quality depends on various reasons, such as maintenance and repair systems. In the proposed model, the defective items are considered, and the goal is to achieve an optimal amount of production in such a way that the costs of the entire system, including production cost, setup, maintenance, inspection, and rework costs, are minimized during a period per unit of time. The numerical results show that increasing the preventive maintenance periods leads to an upward trend in the total cost of the supply chain. Moreover, the sensitivity analysis shows that the longer the preventive maintenance on the machine, the higher reliability of the system as well as total costs will be achieved.

1. Introduction

Economical and profitable production requires comprehensive and accurate planning for all stages of the production system, and the actual behavior is compared and controlled promptly with the situation specified in the plan [1, 2]. These controls help to make the necessary decisions to affect the production systems to get the minimum delay in providing customers' orders. If the production work in the industries is carried out without a plan and subsequent control, productivity will decrease. Moreover, there will be no criteria and standards regarding the performance of different departments. It will cause conflicts within the organization and make the customers dissatisfied. The economic production quantity model helps companies and factories in this field determine the optimal production cumulative size by minimizing the total inventory production costs [1].

The quality and cost of materials that flow from raw to final products are selected as the most important characteristic features in the production systems [2]. In order to adjust these characteristics in the production process, several methods have been prepared for their planning and control. For this reason, manufacturing companies consider organizational units and information systems for production planning and control, inventory control, quality control, and cost control [2, 3].

1.1. Repairs and Maintenance. One of the most important activities to improve the level of access to a production system is the repair and maintenance of the production system. Maintenance and repairs are defined as "a set of activities to maintain or improve the safety, performance, reliability, and availability of the production site of a system or components to ensure their proper performance when needed" [2].

The cost of maintenance includes the following:

(i) Workforce costs for repairs

(ii) The costs of providing spare parts

(iii) Costs of machinery failure (production stagnation) and material waste.

In the technical management and control system of preventive maintenance (PM) affairs, the costs are divided into two types as follows:

(1) Direct costs, such as the cost of workforce hours for repairs (including workers' wages and overhead costs in maintenance and repairs)

(2) Indirect costs, such as the cost of stagnation in production when machines are stopped for repairs or waiting in line for repairs.

In any case, the cost analysis should also consider the capital costs involved in deploying additional machines.

In this research, the hybrid model that will be presented is the combination of determining the amount of economic production and the level of preventive maintenance and repairs, considering the allowed shortage for a production process. The assessed production process is such that after performing operations on a batch of input materials and producing healthy products, a percentage of defective products is generated. Defective products are divided into two categories of defective products with rework ability and nonrework ability through quality checks. Defective products that can be reworked are re-entered into the process and subjected to machining, but defective products that cannot be reworked are considered waste. A machine whose task is to perform machining, based on the policy of preventive maintenance and repairs in each period of production, is stopped by the operator at a specific time and immediately subjected to a preventive maintenance operation by the maintenance and repair department of the organization during an average period of time and continues the machining process. It will resume in the same way as before.

2. Research Background

Zipkin [2] enumerated the assumptions of the Economic Production Quality (EPQ) model as follows: fixed and fixed production rate, fixed and fixed demand rate, fixed preparation and maintenance cost, and unauthorized shortage cost, which are the main and basic assumptions of the model. The purpose of this model is to find the amount of economic production in such a way that the total costs of the system are minimized. Schwaller [3] attributed a certain percentage of a batch of received items to defective parts and also considered an inspection operation with fixed and variable costs.

In 2003, Chiu [4] developed a model by adding the assumption that instead of all defective goods, only a portion of them is reworked to achieve the desired quality, and the remaining quantities are sold at auction prices. He minimized the cost of the system by considering backward demand and a stochastic rate for defective parts, scrap, and rework of defective parts with reworkability in his model. One of the strengths of the abovementioned model is the consideration of rework.

In 2009, Monami et al. [5] presented an economic ordering model for defective quality items under backlog. That paper presented an economic order model for items with a certain percentage of defective items. The percentage of defective items follows a uniform distribution. Moreover, they did not investigate the causes of defective items and maintenance and repairs. Weinstein and Chung [6] presented a model at the production planning level that considered maintenance and repairs. They presented a hierarchical model of production planning considering the cost of maintenance and repairs. In the presented model, side contracts, deficit, and limitation of machinery resources are ignored.

Aghezzaf et al. [7] presented an integrated production and maintenance and repair model for a single production line that minimizes the total cost of emergency repairs. In their model, it is assumed that shortages are not allowed. Aghezzaf and Najid [8] presented an integrated production and maintenance and repair model for multiple production lines that minimize the total cost of emergency repairs with the help of two mathematical models, but this model does not include sales returns. Leung and Chan [9] stated that maintenance is a set of activities to maintain or improve the safety, performance, reliability, and availability of a system or components to ensure proper performance when needed in a production facility.

In 2012, Krishnamoorthi and Panayappan [10] presented an economic production model for a defective manufacturing system with sales returns and reworking. In this model, it is assumed that defective production items enter the rework process. The purpose of that model was to determine the economic order in such a way that the total costs are minimized. Taleizadeh et al. [11] developed an economic production model with random defective items and rework failures, which aimed to obtain the optimal production cycle time and production quantity and backorder quantity for the product.

In 2015, Li et al. [12] investigated the simultaneous deterioration of the product and the production system by reworking the total costs of the production system, which is allowed in this product return model, but the effect of shortage on the total costs of the system was not investigated. Hsu and Hsu [13] presented two economic production models considering incomplete production process, inspection error, shortage, and sales return. They assumed the received items included defective items identified during the inspection. This model aimed to find the optimal amount of production and the maximum amount of shortage. Two numerical examples for the stated model, in the first example, the probability distribution function of the first and second types of inspection error follows a uniform distribution, and in the second example, a beta distribution. Moreover, the model also considers the sensitivity analysis of the effect of the defective probability, the inspection error, maintenance cost, and the shortage.

Shah et al. [14] investigated the effect of the EPQ model for propensity demand with random rework and maintenance time on total system costs, but they did not consider return items in this model and did not allow for shortages. Sadeghi Rad and Nahavandi [15] have introduced a multiobjective mathematical model for order allocation in a multilevel supply chain. In this research, the order discount between different levels is considered. The goals of this model include reducing total costs and reducing the harmful effect on the environment. An exact solution approach has been used to solve this model.

Chen et al. [16] have developed a 2-level robustness model to optimize energy hub inventory considering the economic order model. In the first level, the location of the hub and the energy level are optimized. Rajeswari et al. [17] have developed an economic ordering model for substitute products. In the first step, the life cycle of the products is analyzed, and in the second step, the level of order and maintenance of the products is determined. In this research, the demand is considered as a fuzzy parameter, and the fuzzification error is investigated and analyzed.

Recently, Alimohammadi and Behnamian [18] proposed a scheduling model for preventive maintenance scheduling. This model was optimized using GAMS software. It was claimed that the results of this research could be used to reduce the amount of undistributed energy in the network and subsequently increase subscriber satisfaction. Liu et al. [19] investigated carbon emissions in construction supply chains. In this research, the asphalt supply chain in China was considered, and a scenario-based sensitivity analysis on different parameters with various increasing degrees of abatement levels was implemented. Gholizadeh et al. [20] presented a preventive maintenance model for disposable appliance supply chains under uncertainty. They applied the robust optimization approach to deal with uncertainty in the supply chain. In order to optimize this model, they applied a genetic algorithm and particle swarm optimization.

After reviewing the most important research papers in the field of production and preventive maintenance optimization, the main contribution of this research can be summarized as follows:

(1) Investigating the production, inventory, and preventive maintenance optimization simultaneously
(2) Considering the reworkable and nonreworkable products in the inventory planning
(3) Considering the inventory and shortage in each period of time
(4) Evaluating the effect of parameters on the total cost of the production system.

3. Research Methodology

In this section, a proposed mathematical model is presented in detail. For this purpose, first, the assumptions of the model are introduced. Next, the elements of the proposed model (indices, parameters, and variables) are provided. Finally, the mathematical formulations of the proposed model are presented.

3.1. Model Assumptions. To model any problem, the conditions governing that problem must be known. Therefore, the assumptions of the problem are as follows:

(1) There is a single product system, and the demand is deterministic
(2) The production rate is fixed and is more than the demand
(3) The setup time for the rework process is considered to be zero
(4) The proportion of waste is lower than that of defective goods
(5) The time to perform preventive repairs is considered as a time average in model calculations
(6) Deficiency is considered as a backdrop
(7) In this model, x% of items are defective and are produced at d rate
(8) θ% of low-quality items are considered waste and are not included in the rework process
(9) There is a space limitation for holding items.

3.2. Parameters and Decision Variables. The indices and parameters used in the model include input parameters and decision variables as follows:

3.2.1. Input Parameters

D: Demand rate per unit time

P: Production rate per unit of time

d: Production rate of defective items during the normal process (d = Px)

W: Rate of defective items from the customer ($W = Dy$)

$C0$: Preparation cost per time unit

Ch: Maintenance cost per time unit

Cq: Cost of quality improvement

CR: Rework cost for each unit

Cr: The cost of disposing of each item of waste produced

Cp: Production cost per unit

Cb: Shortage cost for each unit

θ: The ratio of low-quality and defective items that cannot be reworked (waste)

X: Proportion of defective items during the normal process $(0 < x < 0.1)$

y: Proportion of defective items from the customer $(0 < y < 0.1)$

T: Cycle length

$t1$: Production time

$t2$: Rework time

$t3$: The period of time when the production is stopped

$t4$: shortage time

MTTR: Average time required to perform preventive maintenance and repairs (minutes)

γ: Machine maintenance and repair cost rate per unit of time

F: Total available volume or surface

f: Level or volume of each product unit.

3.2.2. Decision Variable

Q^*: Optimum production rate

B^*: Maximum allowed deficiency

3.3. Mathematical Model. The assessed production system has applied PM regarding the machine situations, technical specifications of each machine, and the standards used in its construction. In this case, the machine is put under maintenance operations based on a specific schedule before it has an accidental breakdown during a production period. In this model, It is assumed that during a production period, the machine is stopped once by the operator in the average MTTR time to take the necessary actions.

As shown in Figure 1, $t1$ is the production time, $t2$ is the rework time, $t3$ is the consumption time, and $t4$ is the shortage time. Defective items are identified in each cycle and reworked. In the production process, good and defective goods are produced (at the rate of x) during time $t1$. The line AO represents the slope $P - D - d - W$.

Inventory increases at the rate of P and momentarily decreases at the rate of $D + d$ as the demand and W is the return from the sale by the customer. Therefore, inventory accumulates at the rate $P - D - d - W$. The number of defective items produced at time $t1$ will be equal to the amount of xQ. In this model, it is assumed that θ percent of defective items are considered waste.

Therefore, at the end of time $t1$, the waste $(x\theta Q)$ is identified and separated from the main inventory, and the jK represents this value. The remaining defective items $(Qx(1-\theta))$ will be reworked at the rate of P. $Q1$ is the number of healthy goods that remains after consumption during time $t1$. In fact, $Q1$ and $Q2$ are the inventory on hand after production time $(t1)$ and rework time $(t2)$, respectively which is shown in equations (1) and (2).

$$t_1 = \left(\frac{Q}{P}\right) = \frac{Q_1}{P - D - d - W}, \quad (1)$$

$$Q_1 = (P - D - d - W)t_1 = (P - D - d - W)\frac{Q}{P} - B. \quad (2)$$

The total number of defective items produced at time t_1 is calculated based on equation (3)

$$dt_1 = (Px)\left(\frac{Q}{P}\right) = QX. \quad (3)$$

Rework of low-quality items starts immediately after the end of time t_1 is calculated in equations (4)–(8).

$$t_2 = \frac{MS}{P} = \frac{OJ - JK}{P} = \frac{xQ - xQ\theta}{P} = \frac{(1-\theta)xQ}{P}, \quad (4)$$

$$Q_2 = Q_1 + NS = Q_1 + (P - D - d - W)t_2 = (P - D - d - W)\left(\frac{Q}{P}\right) - B + \frac{(P - D - W)xQ(1-\theta)}{P}, \quad (5)$$

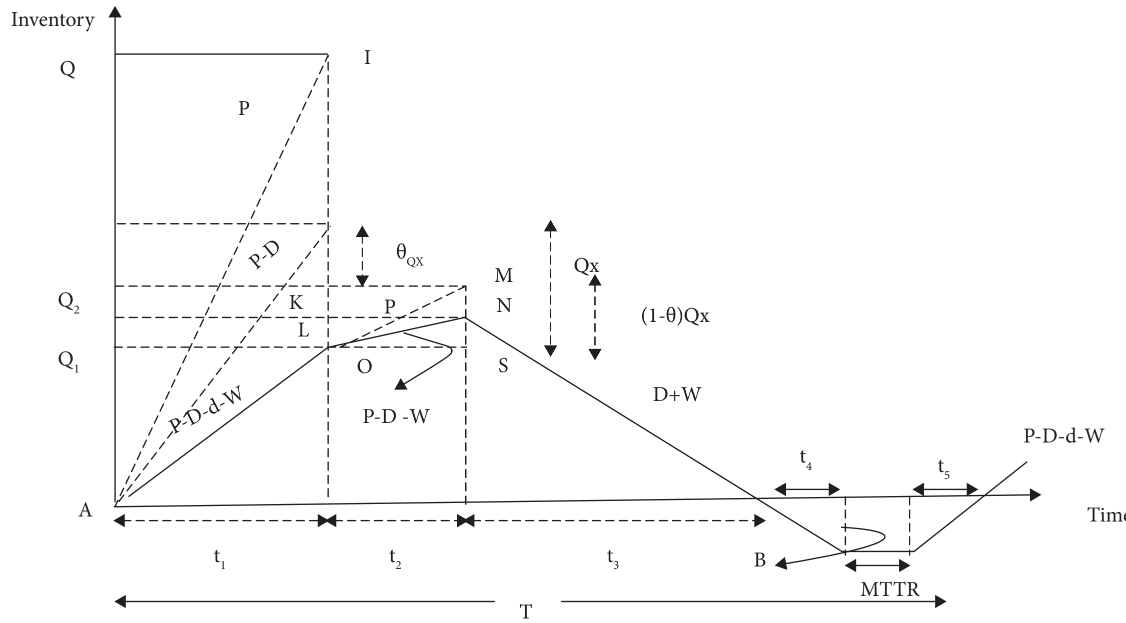

Figure 1: The inventory position of the EPQ model with rework, lack of backlog and the state of PM application.

$$\begin{aligned} t_3 &= \frac{Q_2}{D+W} \\ &= \frac{1}{D+W}\left[(P-D-d-W)\left(\frac{Q}{P}\right) - B + \frac{(P-D-W)xQ(1-\theta)}{P}\right], \end{aligned} \tag{6}$$

$$t_4 = \frac{B}{D+W}, \tag{7}$$

$$t_5 = \frac{B}{P-D-d-W}. \tag{8}$$

The time of a period (the interval between two operations starts) is obtained from the total production time, rework, product consumption, and shortage, as well as the average time spent on maintenance and repairs, which is calculated in equation (9).

$$\begin{aligned} T &= \sum_{i}^{5} t_i + \text{MTTR} = \frac{Q}{D}[1 - X + X(1-\theta)] + \text{MTTR} \\ &= \frac{Q}{D}(1 - x\theta) + \text{MTTR}. \end{aligned} \tag{9}$$

It should be noted that when $\theta = X = 0$, then $T = Q/D + \text{MTTR}$ becomes.

3.4. Cost Calculation. The following mathematical formulation is presented to calculate the system's total costs, including the cost of startup and maintenance.

3.4.1. Setup Cost. In each period, the production process starts with a fixed cost of C_0. Therefore, the cost of setting up the process during a period per unit of time is equal to equation (10).

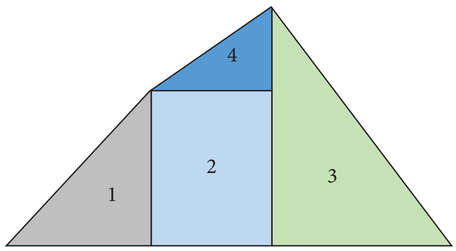

Figure 2: Inventory level.

$$SC = \frac{C_0}{T}. \quad (10)$$

3.4.2. *Maintenance Cost.* The average inventory per unit of time is calculated from the sum of the areas in Figure 2. Accordingly, the inventory is divided into four segments, and the amount of inventory is calculated in equations (11)–(14), and the total inventory level is equal to equation (15)

$$S_1 = \frac{1}{2} Q_1 t_1, \quad (11)$$

$$S_2 = Q_1 t_2, \quad (12)$$

$$S_3 = \frac{1}{2} t_1 (Q_2 - Q_1), \quad (13)$$

$$S_4 = \frac{1}{2} Q_2 t_3, \quad (14)$$

$$\begin{aligned} S_1 + S_2 + S_3 + S_4 &= \left[\frac{1}{2} Q_1 t_1 + Q_1 t_2 + \frac{1}{2} t_1 (Q_2 - Q_1) + \frac{1}{2} Q_2 t_3\right] \\ &= \frac{1}{2}\left[\left\{(P - D - d - w)\frac{Q}{P} - B\right\}\frac{Q}{P} + 2\left\{(P - D - d - w)\frac{Q}{P} - B\right\}\right. \\ &\quad \cdot \frac{xQ(1-\theta)}{P} + \frac{(P - D - w)x^2 Q^2 (1-\theta)^2}{P^2} \\ &\quad \left. + \frac{1}{D + W}\left\{(P - D - d - w)\frac{Q}{P} - B + \frac{(P - D - w)x(1-\theta)Q}{P}\right\}^2\right] \\ &\quad - \frac{1}{2P^2(D + W)}\left[P(D + W)BQ + 2P(D + W)BxQ(1-\theta) - P^2B^2\right. \\ &\quad \left. + 2P(P - D - d - w)QB + 2P(P - D - w)xQB(1-\theta)\right] \\ &= \frac{Q^2}{2PD}\left[P(1 - \theta X)^2 - D(1 + y)\left(1 + x - 2x\theta + X^2(1-\theta)^2\right)\right] \\ &\quad - \frac{BQ}{2PD}\left[2P(1 - \theta x) - D(1 + y) + \frac{B^2}{2D}\right]. \end{aligned} \quad (15)$$

As a result, the cost of maintaining inventory during a period per unit of time is calculated based on equation (16).

$$HC = C_h \cdot \frac{C_h}{T}\left[\frac{Q^2}{2PD}\left[P(1 - \theta x)^2 - D(1 + y)\left(1 + x - 2x\theta + x^2(1-\theta)^2\right)\right] - \frac{BQ}{2PD}\left[2P(1 - \theta x) - D(1 + y)\right] + \frac{B^2}{2D}\right]. \quad (16)$$

3.4.3. *The Cost of Shortage per Unit of Time.* According to Figure 1, in order to calculate the shortage cost, it is first necessary to calculate the average shortage in the cycle. Since at time $t1$ or $t3$, the inventory level in the hands of the system is positive. In this period, the production system will not face a shortage. Only at times $t5$ and $t4$ the demand faces a shortage. The average shortage during a period per time unit is calculated from the sum of the areas in Fig. 3 as follows:

The shortage level is obtained from the sum of the three levels and is calculated based on equations (17)–(19).

$$S_1 = \frac{1}{2}Bt_4, \tag{17}$$

$$s_2 = \text{MTTTR}.B, \tag{18}$$

$$S_3 = \frac{1}{2}Bt_5, \tag{19}$$

$$\begin{aligned} B_S &= S_1 + S_2 + S_3 \\ &= \frac{1}{2}Bt_4 + \text{MTTTR}.B + \frac{1}{2}Bt_5 \\ &= \frac{B^2(P-D)}{2(P-D-d)} + \text{MTTR} * B. \end{aligned} \tag{20}$$

Therefore, the cost of backlog shortage per unit of time is calculated as equation (21).

$$\begin{aligned} BA &= C_b.\overline{B_s} \\ &= \frac{C_b}{T}\left[\frac{B^2\,(P-D)}{P-D-d} + \text{MTTR} * B\right]. \end{aligned} \tag{21}$$

3.4.4. Production Cost per Unit of Time. The cost of producing goods during a period of time is calculated using equation (22).

$$PC = \frac{C_pQ}{T}. \tag{22}$$

3.4.5. PM Const and Repairs per Unit of Time. The cost of performing preventive maintenance and repairs on the machine during a period per unit of time is equal to equation (23).

$$MT = \frac{\gamma\text{MTTR}}{T}. \tag{23}$$

3.4.6. Quality Check Cost for Defective Items. The quality of defective items is checked and classified into two groups: waste and reworkable. The cost of quality inspection for defective items is equal to equation (24).

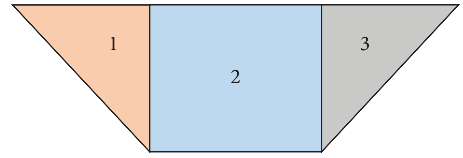

FIGURE 3: Shortage level.

TABLE 1: The value of each effective parameter.

Parameter	Value
D	4500 unit/year
C_h	\$10
C_o	\$100
CQ	\$5
C_R	\$5
C_r	\$1
CP	\$50
C_b	\$10
θ	0.2
X	0.001
γ	20
Y	0.001
f	0.9 m^3
MTTR	0.222
F	900 m^3

$$\begin{aligned} QC &= \frac{\theta C_Q d t_1}{T} \\ &= \frac{\theta C_Q Q x}{T}. \end{aligned} \tag{24}$$

The rework cost for low-quality (defective) items that can be reworked is equal to equation (25).

$$RC = \frac{(1-\theta)QxC_R}{T}. \tag{25}$$

Poor quality and defective items that are placed in the waste group will not be able to be reworked. The cost of disposal of items that are considered waste will be as equation (26).

$$rc = \frac{\theta QxC_r}{T}. \tag{26}$$

Therefore, the total cost of the system per unit of time is obtained from the sum of the costs of setup, maintenance, shortage, inspection, preventive maintenance, rework, waste disposal and the quality cost of defective items, which is shown in equation (27).

$$\begin{aligned} TC = \frac{1}{T}\Bigg[C_0 + C_h\left[\frac{Q^2}{2PD}\left[P(1-\theta x)^2 - D(1+y)\left(1 + x - 2x\theta + x^2(1-\theta x)^2\right)\right] - \frac{BQ}{2PD}(1-\theta x) - D\,(1+y)\right] + \frac{B^2}{2D}\Bigg] \\ + C_b\left[\frac{B^2(P-D)}{2(P-D-d)} + \text{MTTR} * B\right] + C_pQ + \gamma\text{MTTR} + \theta C_Q Qx + (1-\theta)\,QxC_R + \theta QxC_r. \end{aligned} \tag{27}$$

Table 2: The optimal solution of the proposed mathematical model.

	Q^*	T^*	TC^*
LINGO	1000	0.44	227014.1

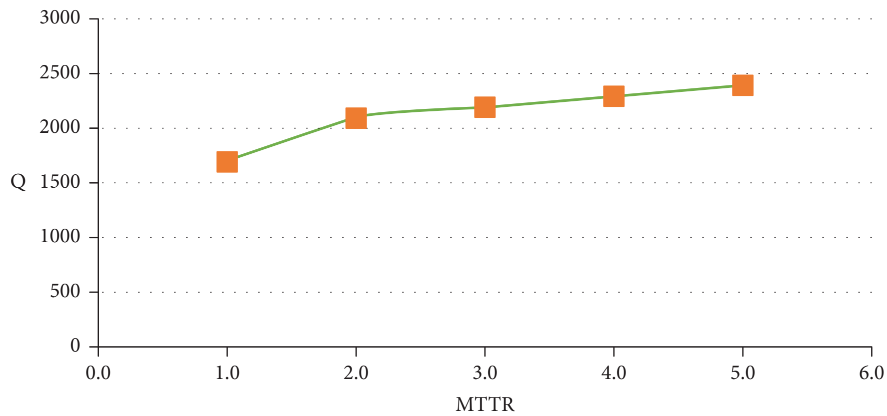

Figure 4: The effect of MTTR on the amount of economic production order.

By placing T in equation(27), the cost function will be in the form of equation (28).

$$TC = \frac{DC_0}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{DC_h}{Q(1-x\theta)+(\mathrm{MTTR}*D)}\left(\frac{Q^2}{2PD}\left[P(1-\theta x)^2 - D(1+y)\left(1+x-2x\theta+x^2\right)(1-\theta x)^2\right]\right) - \frac{BQ\,DC_h}{2PD(Q(1-x\theta)+(\mathrm{MTTR}*D))}\left[2P(1-\theta x)-D(1+y)\right] + \frac{B^2C_h}{2(Q(1-x\theta)+(\mathrm{MTTR}*D))} + \frac{B^2(P-D)C_b}{2(P-D-d)(Q(1-x\theta)+(\mathrm{MTTR}*D))} + \frac{D(\mathrm{MTTR}*B)}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{C_PQD}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{D\gamma\mathrm{MTTR}}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{D\theta C_QQx}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{D(1-\theta)QxC_R}{Q(1-x\theta)+(\mathrm{MTTR}*D)} + \frac{D\theta QxC_r}{Q(1-x\theta)+(\mathrm{MTTR}*D)}. \tag{28}$$

3.5. Constraints. In most inventory models, it is assumed that there are no restrictions such as storage capacity, holding time, etc., while any of these constraints may exist in the real world. For example, it is possible that the storage capacity is limited; in this case, constraints are placed on the storage level or otherwise. Equation (29). shows the limitation of warehouse capacity to store items.

$$F \times Q \leq F. \tag{29}$$

It should be noted that the optimal solution of the proposed mathematical model can be found by finding the extreme point of the cost function, which has been proved in Appendix.

4. Numerical Results

In order to analyze, better understand and validate the presented model, a numerical example whose parameter values are determined based on Krishnamoorthi and Panayappan [10] with slight changes is solved and analyzed.

In this regard, the selected value for each effective parameter is provided in Table 1.

According to the solution of the proposed model based on the above data, the obtained results are according to Table 2.

The results in Table 2 shows that the best ordering quality is 1000 unit of products, and the period of ordering is 0.44 of a year. In this solution, the optimal value of the objective function is 224014.1, which is the least total cost of the production system.

4.1. Sensitivity Analysis. The sensitivity analysis is applied to analyze the model and investigate the effect of some important and influential parameters on the optimal solution of the proposed model.

4.1.1. Sensitivity Analysis of Maintenance Time (MTTR). In order to study the effect of repair and maintenance time on the optimal solution of the presented model, we use the sensitivity analysis of the parameter MTTR. The model increases

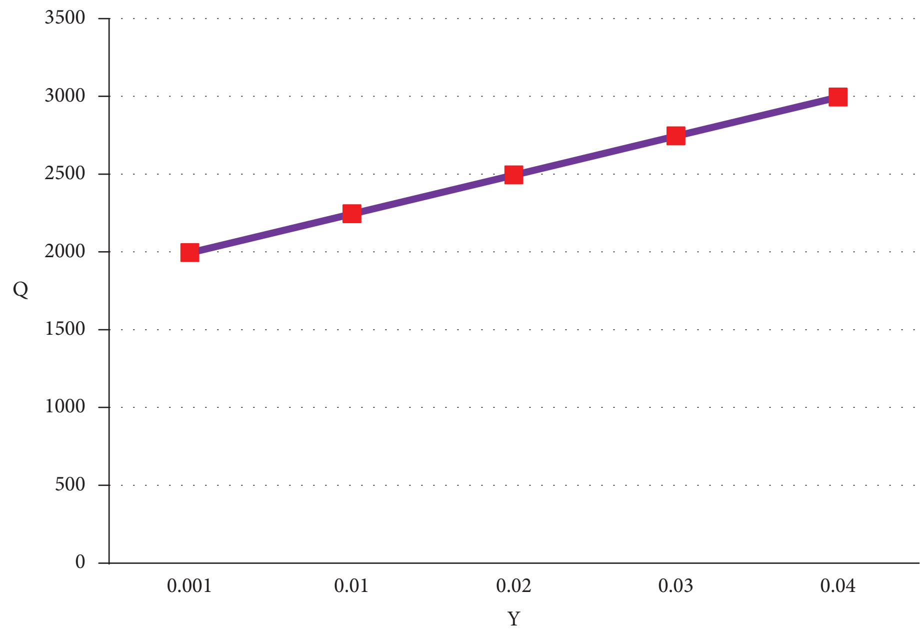

Figure 5: The effect of parameter Y on the amount of economic production order.

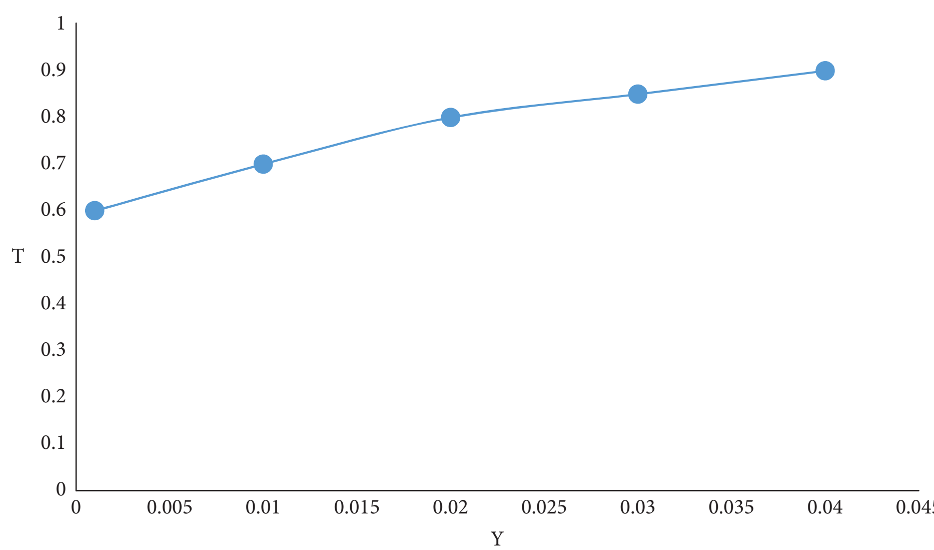

Figure 6: The effect of parameter Y on the time of economic production order.

and decreases the maintenance time by a fixed amount. The results of this sensitivity analysis are shown in Figure 4.

As it is clear from Figure 4, with the increase in the time of repairs and preventive maintenance, the curve first has a steep slope and then has an upward trend with a gentler slope. This curve shows that the longer the time of preventive maintenance on the machine, the more accurately and at a higher level it will lead to an increase in the optimal production rate.

4.1.2. Sensitivity Analysis for Parameter ? (Proportion of Defective Items from the Customer). The sensitivity analysis is implemented in order to investigate the effect of the proportion of defective items from the customer on the economic order and the optimal production time.

As can be seen in Figures 5 and 6, with the increase in the proportion of defective goods from the customer (Y), the optimal amount of the order (Q^*) and the optimal time (T^*) will also increase.

5. Discussion and Conclusion

Determining the optimal size of the production batch in such a way that the total costs are minimized has always been one of the main topics of scientific and industrial research [21–23]. In addition, nowadays, in industrial units, due to the competitiveness of production and the need to reduce costs and deliver goods on time, equipment availability and the prevention of unexpected stops are of particular importance.

Investigation and research on the number of economic production, minimization of production costs and related issues have continued from the past to the present. So far, lots of optimization models have been presented in this field. Among the issues that have not received much attention is the issue of production machine breakdowns. It is evident that the production machine may encounter a breakdown during production, which justifies the necessity of applying a proper maintenance and repair policy.

In recent years, one of the basic foundations in any organization is equipment, machinery and human resource [24]. On the other hand, to increase productivity and efficiency, provide services and achieve global standards, special attention should be paid to increasing the efficiency of machines and reducing the costs of repairing and stopping machines. Therefore, research in this field is receiving more attention.

In real-world conditions, the success of organizations in providing services and increasing their quality depends on various reasons for having a maintenance and repair system. It is suitable for one of the essential topics of every organization.

The presented mathematical model combines the determination of the economic production amount and the level of preventive maintenance and repairs, taking into account the allowed shortage for a production process. A production system is intended to produce a product item. The production process is such that after performing operations on a batch of input materials, in addition to producing healthy products, a percentage of defective products are also produced. In this research, defective products are divided into two categories through quality inspection: defective products with reworkability and non-reworkability (waste). Defective products with reworkability are re-entered into the process and subjected to machining, but defective products are not reworkable and are considered waste.

In order to show the managerial insights of this research, it can be indicated that based on the preventive maintenance policy, the repairs in each period of production are stopped by the maintenance and repairs department of the organization during an average time. This stoppage of production leads to disruption in the process of meeting the needs of customers. Accordingly, determining the appropriate time for preventive maintenance, in addition to reducing the costs of the production system, can have the least issue in meeting the demand.

In order to extend this research for future research, the following developments are suggested.

(1) Increase the number of supply chain echelons and consider the supplier, producer and buyer together.

(2) Considering several suppliers and buyers simultaneously, which in this case makes the model closer to the real world.

(3) Considering the production of the multi-product in the preventive maintenance planning

(4) Considering the fuzzy state for production rate and demand parameters.

(5) In addition to the limitation of warehouse space, other constraints, such as budget and raw material supply, can also be considered to be closer to the real world.

Data Availability

The data used in this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

In the provided Appendix, proof of the convexity of the cost function is provided. In other words, in order to ensure that a local solution obtained is also its absolute minimum solution, the convexity of this function will be checked. (*Supplementary Materials*)

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Research Article

The Relationship between Big Data Analytic-Artificial Intelligence and Environmental Performance: A Moderated Mediated Model of Green Supply Chain Collaboration (GSCC) and Top Management Commitment (TMC)

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Academics and practitioners have shown growing interests in big data analytics and artificial intelligence (BDA-AI) in recent years. Despite this, research on the application of BDA-AI for green supply chain collaboration (GSCC) and its influence on environmental performance (EP) is still limited. The current research addresses this gap and extends organizational information processing theory by incorporating BDA-AI and exploring top management commitment (TMC) as a moderator. The current study developed a moderated mediation model based on 402 samples of data from Turkish manufacturing firms. The result revealed that the application of BDA-AI has a positive impact on GSCC and EP. The results also indicated that GSCC has a positive impact on EP. Our findings revealed that GSCC mediated the association between BDA-AI and EP. The results also revealed that TMC moderated the positive relationship between BDA-AI and GSCC, such that the strength of the positive relationship is further intensified at higher levels of TMC. The results also show that TMC moderated the positive relationship between BDA-AI and EP, such that the strength of the positive relationship is dampened at lower levels of TMC; significant findings have not been outlined in the extant literature. The current research will assist supply chain and logistics managers and top management in deploying BDA-AI technology to support GSCC and improve EP.

1. Introduction

The application of big data analytics has drawn a lot of interest in both theory and practice in the last decade [1]. Papadopolous and Gunasekaran [2] attributed this to the rapid growth of information technology, which has enabled big data to gain key relevance and has grown to be among the most beneficial resources in several organizations. Additionally, organizations are going digital, and as a result, their supply chains are generating a large volume of data [3, 4]. According to Papadopolous et al. [5], the growth in data has prompted several organizations to build data analytics techniques such as big data analytics (BDA) to turn the data into meaningful information that would aid decision-making and boost their supply chain efficiency. However, for the environmental dimension, studies examining the impacts of BDA on the supply chain are still in their early stages [6]. With a few notable exceptions [6, 7], the number of empirical studies that have shown the effects of big data on green supply chain collaboration (GSCC) and environmental performance (EP) are still limited.

According to numerous researchers, integrating the environment into the supply chain provides organizations with a competitive advantage [8, 9]. However, the process is complex [9] and requires the collaboration and coordination of numerous organizations working together to achieve their desired goals [10]. It is important for all industries to improve their environmental performance (EP), but it is especially important for the manufacturing industry, which is a major source of pollution all along its supply chain.

The Turkish manufacturing industry is an important aspect of the country's economic development, acting as a catalyst for modernization and generating multiplier effects. However, several studies have indicated that the manufacturing sector generates emissions that cause environmental pollution [11, 12]. Thus, the manufacturing sector must identify ways to optimize material usage and improve operational processes [13]. When aiming for green initiatives, organizations must think from the perspective of their supply chain [14], especially in the manufacturing sector. A significant challenge that makes it more difficult to achieve green initiative results is the supply chain's members' involvement and participation [15]. So, managing the supply chain well is a key part of making sure that green initiatives in the manufacturing sector work.

BDA capabilities, powered by artificial intelligence, will drive the future of supply chain computerization to increase the visibility of green supply chains [16, 17]. This would make it highly helpful for the manufacturing sector to gain knowledge on how to apply big data analytics approaches and concepts in establishing environmental initiatives. Additionally, big data analytics can facilitate large-scale group decision-making techniques in a circular economy [18]. From this point of view, it makes sense to think that GSCC may be a link between BDA-AI and EP.

Despite the numerous studies on the importance of BDA-AI in manufacturing research, which aids organizations in cost reduction [19], increasing production speed [20], and developing new services or products in response to changes in the needs of consumers [21, 22], research on using BDA-AI in promoting manufacturing supply chain processes, especially green practices, is still very limited. Therefore, the current study focuses on the impact of BDA-AI in improving environmental performance in the manufacturing sector, an area that, to our knowledge, has received little research attention.

Furthermore, as a result of mounting pressure from both internal and external stakeholder groups, organizations' leaders are now held accountable for establishing cleaner operations [23]. This further demonstrates that environmental concerns have clearly become top priorities for corporations [24]. Additionally, top management's roles in green supply chain initiatives have received little attention [25]. In relation to sustainable supply chain management, the extent to which top management commitment plays a role in the link between BDA-AI technology and EP has not been rigorously empirically explored [6], especially in Turkey. To address these gaps, the current study developed a moderated mediation model that tested the mediating role of GSCC and the moderating role of top management commitment in the relationship between BDA-AI and EP in the context of the Turkish manufacturing sector. Figure 1 shows the conceptual model of the study and the proposed hypotheses.

2. Theoretical Rationale and Hypotheses Development

2.1. BDA. It is challenging to come to an agreement on a definition given the current widespread acceptance of BDA and the usefulness of its applications. According to Mikalef et al. [26], there is a new generation of technologies and architectures that facilitate high-velocity data capture, discovery, and analysis with the aim of economically extracting value from very large amounts of a wide variety of data. It uses innovative algorithmic methods and practices that enable organizations to analyze and make sense of crucial business data in order to better understand their operations and the market [2]. Therefore, it enabled them to gain a competitive advantage [19]. Among these advantages, there are supply chain and logistics management [2]. So, it is not surprising that researchers in management science and supply chain and logistics management have started to pay attention to BDA. Brynjolfsson et al. [27] attributed this to its ability to employ techniques that allow decision makers to arrive at improved decisions founded on evidence as opposed to intuition or human judgement. It necessitates the establishment of proper tools to handle the potential amount of data and, as a result, detect trends and uncover models to obtain advantageous outcomes [17]. The study by Choi et al. [28] distinguished three types of data processing schemes, namely, batch processing, real-time flowing processing, and interactive processing. BDA-related systems can be used in various areas of analysis, including descriptive, predictive, and normative analysis [29].

Through the combination of methods, tools, and processes, BDA helps firms make effective decisions regarding green initiatives in their supply chain [30]. Even so, the impact of BDA on GSCC and EP's decision-making processes is not well understood or established in the literature.

2.2. Green Supply Chain Collaboration in the Manufacturing Sector. Green supply chain management (GSCM), which combines studies on green management and supply chain management, is used to address environmental issues in organizations and their supply chains [31]. Every day organizations are confronted with pressures from the media, surrounding communities, nongovernmental organizations, and legal requirements enforced by environmental legislation [32]. Additionally, consumers are calling for greater accountability and transparency regarding the circumstances surrounding the manufacture and distribution of their goods. They also call for greater environmental sensitivity [32]. As a result, organizations are compelled to make significant efforts to create a more sustainable supply chain and reevaluate how they conduct their business as they become more aware of their obligation to ensure the long-term survival of humanity [33, 34]. So, for green

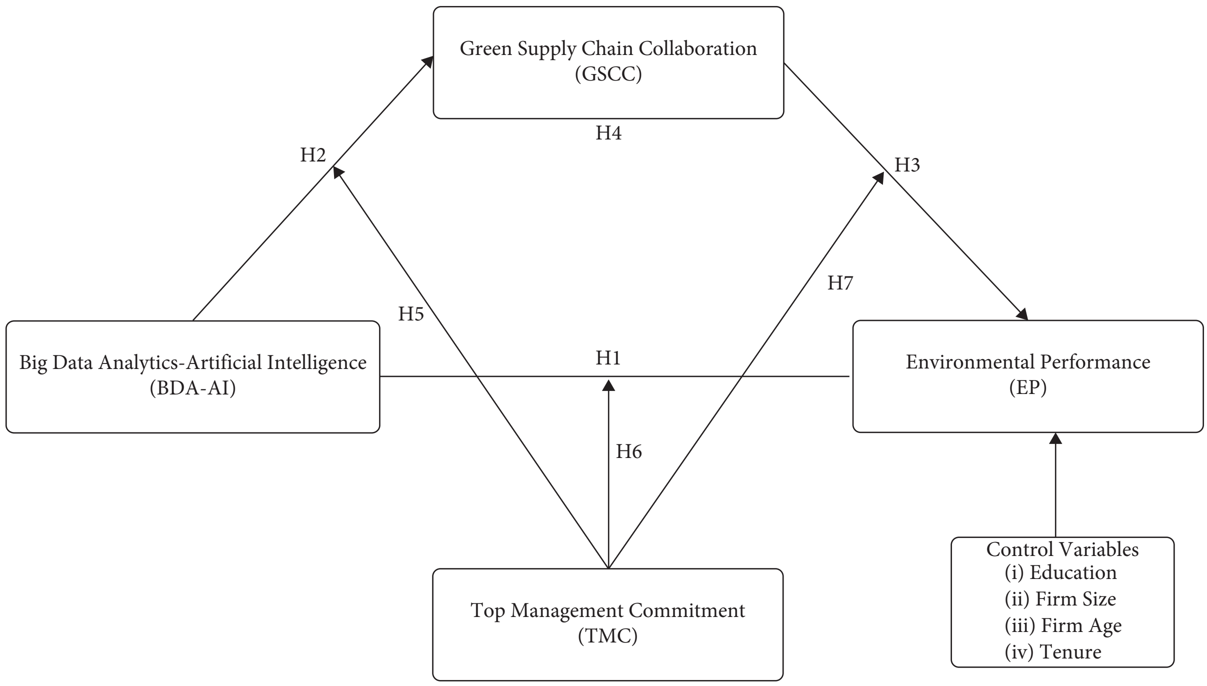

Figure 1: Conceptual framework.

management to happen, companies need to focus on the supply chain instead of the organizations themselves [14]. This is especially important in the manufacturing sector, where pollution has a big effect on the environment.

In a circular economy, GSCC relates to the degree to which organizations and their suppliers contribute to enhancing environmentally friendly decision making and performance, such as through the design of environmentally friendly products, the production and recycling of materials, the handling of waste, and the reusing of materials all through the life cycle of flow [35]. In the manufacturing sector, GSCC requires the synchronization and collaboration of several organizations [36]. Thus, the probability of achieving green initiatives within the supply chain increases with the degree of consultation and collaborative relationship between supply chain partners [37]. Also, the earlier study by Chen and Chen [38] advocated the use of collaboration among supply chain members so as to share knowledge, rationalize core business processes, and streamline interorganizational operations. However, Corso et al. [39] emphasized that several organizations are yet to comprehend the primary factor that allows organizations to implement green supply chain collaborative efforts. This study, however, proposes that the use of advanced technology (BDA-AI) can equip the manufacturing supply chain with the capacity to enhance flow management, processes, and cross-organizational relationships with the aim of attaining environmental performance.

2.3. Big Data Analytic-Artificial Intelligence in the Manufacturing Sector. Although there is a significant amount of literature on the adoption of emerging technologies [7], the research on the role of the adoption of emerging technologies (BDA and BDA-AI) on environmental performance remains relatively scarce in the manufacturing sector. Artificial intelligence and its technologies have been extensively utilized in the supply chain context since SCM has become more data intensive and its concerns have been aimed toward the substitution of assets (such as inventory, warehouses, and transport equipment). The benefits acquired in this domain in the manufacturing sector are abundant, including faster production, cost optimization, and the creation of new products [19, 21, 22]. Apart from its operational benefits, the combination of BDA and AI provides an encouraging window of opportunity for manufacturing sector studies. The combination of BDA and AI has already been proven efficient in the manufacturing sector, most notably in the creation of new products and services [22]. Thanks to the ability to process information faster, the manufacturing sector can better plan its resources. These benefits provide a significant benefit for controlling flows and procedures in the manufacturing supply chain, including transportation and warehousing, internal production, and waste handling sorting and treatment. In this study, the use of BDA-AI means using BDA mixed with AI to get more useful information so that organizations can improve their ability to make decisions [7].

Furthermore, the manufacturing supply chain has widely used organizational information processing theory [40]. The theory has not, however, been empirically applied in the particular research field of manufacturing green supply chains [6]. Given the complex nature of the manufacturing supply chain (such as inventory, warehouses, and transport equipment). The use of OIPT as a theoretical framework was appropriate. By using information processing mechanisms, the theory offers a sound foundation regarding the interpretation of the concept of organizational behavior in businesses [41]. Consequently, Galbraith [42] stated that technology infrastructure can enhance organizations' information processing capabilities. Based on this and considering the complexity of the manufacturing sector, we suggest BDA-AI techniques should develop information processing capacity to best support green decision-making. Dubey et al. [43] say that despite the opportunities that BDA-AI offers, many organizations have not been able to use it effectively to promote green supply chain operations.

2.4. BDA-AI and Environmental Performance. According to Wu and Pagell [44]; big data analytics powered by artificial intelligence play an important role in green supply chain management by removing information asynchronization and handling complex environmental data. Therefore, it offers insights for decision-making processes in order to promote green supply chain management and EP [45]. Chiarini's qualitative study (2021) found that AI and analytics are important for analyzing and finding patterns in data, predicting the effects on the environment, and reducing energy use, all of which improve environmental performance.

A number of researchers have suggested that the application of BDA is crucial in integrating environmental initiatives into several supply chain activities. For example, Lee and Klassen [46] argued that BDA can be very helpful in manufacturing, storing, and waste management, thus improving EP. The use of BDD-AI in the context of green supply chain management through eco-design and supplier selection has been reported to promote environmental performance [47]. Liu et al. [48] and Singh et al. [49] also say that BDA-AI improves internal green operations and supplier collaboration, which both reduce waste, emissions, and environmental risks.

Most of the abovementioned studies only offered a theoretical explanation of the relationship between BDA-AI and EP, and several of these studies were conducted outside the manufacturing sector. Thus, building on the existing literature, we hypothesize that:

> H1: BDA-AI empowered decisions has a positive impact on EP.

2.5. BDA-AI and GSCC. Recent years have seen a significant increase in the use of BDA in the green supply chain across a wide range of fields [5, 50]. Fernando et al. [51] pointed out that effective data synchronization in supply chain management has become a challenge. In order to achieve business objectives, supply chain partners are constantly willing to integrate and coordinate business processes [52]. However, difficulties with the sharing of information in the supply chain have always existed, including information delay, information distortion, and information loss [53]. From this standpoint, Song et al. [54] suggested that the application of big data analytics promotes visibility and green integration in supply chain management as well as the accessibility of valuable information.

BDA can aid in effective data collection, assimilation, and reporting [55] and enhance sustainability when designing products [43]. Singh et al. [49] combined big data analytics, cloud computing, and operations research techniques (AHP, TOPSIS, and DEMATEL) to create a new tool for decision-making that can measure carbon footprints and greenhouse gas emissions when choosing suppliers. Additionally, in the hospital sector, Benzidia et al. [6] reported that BDA-AI-empowered decisions are positively related to GSCC.

In line with the reasoning above and empirical evidence, we endorse the notion that the use of new BDA-AI technologies can help the manufacturing sector in processing data from intra- and cross-organizational sources, as well as creating avenues for collaboration with suppliers in the process of making environmental decisions. Thus, we hypothesize that:

> H2: BDA-AI empowered decision has a positive impact on GSCC.

2.6. Green Supply Chain Collaboration and EP. Previous research [56, 57] has shown the link between environmental integration and supplier collaboration to ensure long-term environmental performance. However, no research has focused on this link in the context of the Turkish manufacturing sector, even though this topic has become more important in recent years.

Supplier collaboration relates to a common understanding that includes resource sharing and decision-making with the aim of reducing environmental impact on the product development process [58]. From this standpoint, Zhu et al. [35] suggested that organizations should allocate more resources to research and development and collaborate with suppliers to attain environmental performance. Supplier collaboration, which has been empirically demonstrated by a number of studies [58, 59], is a critical factor for firms looking to integrate low-carbon emission resources and operations and minimize their energy and environmental footprint. In a similar way, Zhu et al. [35] said that a cross-collaboration strategy can help businesses cut down on waste, improve their environmental performance, and build a reputation for being green.

A GSCC improves the level of monitoring of suppliers who promise to provide and use environmentally friendly equipment and raw materials [60]. Furthermore, adopting a collaborative approach with suppliers in the manufacturing sector appears to be crucial in order to promote green purchasing and supply practices as well as manage potential demands and transportation. These procedures can enhance inventory management, warehouse storage, and transportation while minimizing manufacturing waste disposal. Thus, we hypothesize that:

> H3: Green supply chain collaboration has a positive impact on EP.

2.7. The Mediating Role of GSCC. Due to growing pressures, increasing challenges, and the desire to meet ever-changing customer needs, manufacturing companies are forced to think about implementing green supply chain practices with the aim of improving their EP [61]. Laosirihongthong et al. [62] pointed out that the design stage is the most crucial phase of the product lifecycle because it is where environmental concerns can be addressed. Designing re-useable and recyclable items through the use of low-energy processes will enhance waste management and minimize hazardous materials and toxic emissions [63], thus promoting environmental performance. With respect to green operations, organizations can collaborate with their suppliers to match environmental requirements with product design, manufacturing processes, and transportation [64]. Also, Benzidia et al. [6] pointed out that BDA-AI can help make green decisions and is an important tool for managing environmental concerns within and across organizations.

Prior studies [47, 49] suggested that BDA-AI enables intra-organizational green initiatives and suppliers' collaborations, leading to minimized waste, carbon emissions, and environmental concerns. To summarize, it is reasonable to infer that BDA-AI can trigger GSCC and that green supply chain collaboration would result in environmental performance. That is, GSCC may mediate the link between BDA-AI-powered decisions and EP. To date, no prior studies have investigated the mediating role of GSCC in the link between BDA-AI-empowered decisions and EP. In line with theoretical and empirical evidence, we posit that:

> H4: Green supply chain collaboration mediates the association between BDA-AI empowered decisions and environmental performance.

2.8. Moderating Role of TMC. The concept of TMC resonates with the Theory of Planned Behavior (TPB), which describes behavior based on an individual's will [65]. When an individual's activity has a goal and purpose, TBP behavioral performance occurs. An individual's behavior is the result of a logical cognitive process in which the individual assesses information internally before applying it to its external behavior [65]. From this point of view, it has been said that the knowledge and beliefs of top management affect how organizations use new technologies like big data analytics [66] and that managers' concerns about the environment affect how much green innovation operations affect EP and competitive capabilities [67].

It is one thing for organizations to portray themselves as eco-friendly while carrying out their usual activities [68]. However, it is another thing for top management to commit to the economic and environmental effects of their activities [69]. Li et al. [70] suggested that top management leaders must genuinely believe in sustainability if they are to translate the call of stakeholders for green operations into an efficient response with lasting results. Furthermore, a strong top management moral stance and its perceptions regarding the environment [71, 72] may largely instill positive ideologies on green practices in their supply chain practices and EP [24]. Therefore, the key components for the success of green practices are top management's "support for, leadership in, and commitment to sustainability" [23, 73].

Genuine leaders discover opportunities, provide purposeful vision, and amend the code of conduct of their operations in their respective fields [74]. From this standpoint, Wisner et al. [75] stated that commitment has to start at the upper echelons of management. Consequently, establishing appropriate strategic guidelines and building a green operation will certainly be impossible without TMC [25]. Indeed, numerous studies reported that several green initiatives had strongly failed due to a lack of support from top management [76, 77]. Thus, in order to establish green initiatives, management should incorporate sustainable initiatives into daily supply chain activities [78] to instigate environmental reasoning throughout the company [79].

In line with the arguments above, we hypothesize the following;

> H5: Top management commitment moderates the relationship BDA-AI and GSCC, such that the positive relationship is stronger for higher than lower level of top management commitment.
>
> H6: TMC moderates the relationship between BDA-AI and EP, such that the strength of the positive relationship is reduced for lower level of TMC.
>
> H7: TMC moderates the relationship between GSCC and EP, such that the strength of the positive relationship is further enhanced for higher level of top management commitment.

3. Methods

3.1. Sample and Procedures. Data collected through the cross-sectional method was utilized to examine the current research's conceptual model. With the help of nine (9) experts from manufacturing firms in Turkey, the questionnaire survey was pre-tested for face validity. These experts, who were well experienced in manufacturing supply chain management and logistics, participated in the pre-test we conducted. We asked these experts to assess the survey's structure, comprehensibility, imprecision, and wholeness [43]. This enabled us to clarify some questions regarding the measurement items. The inputs and suggestions from the experts were included in the final questionnaire. In order to prevent difficulty in understanding the questions, participants were given a glossary of key terms. The participants were then told that their information would be kept secret and that the data collected would only be used for academic research.

Consistent with Chen et al. [38]; in developing the measurement scale, a number of measures were followed, and a pre-test was carried out, as mentioned earlier. We had to make sure the measurement scale's content was valid as a first step. The purpose of content validity was to determine if or not the various questionnaire items sufficiently represented the phenomenon under examination. In doing so and before purification, we developed a questionnaire and measurement scales for our study's observed variables using the academic literature as a guide. All the constructs of the current research were evaluated on a 5-point Likert scale, from strongly disagreeing (=1) to strongly disagreeing (=5).

A total of 994 questionnaires were sent out, and 402 complete responses were retrieved, yielding a response rate of 40.44%.

Prior to administering the questionnaire survey, each participant was pre-selected through the use of closed-ended questions regarding their knowledge of BDA capabilities with respect to the supply chain. The questionnaire survey was sent out to participants who were in charge of supply chain and logistics activities within the manufacturing firms in Turkey. The survey was administered online via a Google form.

The demographic information is outlined in Table 1. Regarding gender, 341 (84.90%) of the participants were male and 61 (15.10%) were female. The majority (280, or 69.6%) of the participants had at least a bachelor's degree. Majority 344 (85.6%) of the firms surveyed had above 20 employees. The majority of 375 (93.0%) of the participants have been with their company for over 6 years, implying that they have the required experience to evaluate the survey. Based on the type of business their firm conducts: food and consumer goods 113 (28.10%), machinery and industrial equipment 110 (27.40%), chemicals 68 (16.90%), automotive components 56 (13.90%), and pulp and paper 55 (13.70%).

3.2. Measures. BDA-AI was measured using four items developed by Srinivasan and Swink [30] and Dubey et al. [43].

GSCC was measured using four items developed by Singh and El-Kassar [80].

TMC was measured using five items developed by Chen and Paulraj [81] and Dubey et al. [82].

EP was measured using six items developed by Longoni et al. [83]; and Singh and El-Kassar [80].

3.3. Data Analyses. The Statistical Package for Social Science (SPSS) 28.0 and AMOS 28 software were employed to analyze the data collected for this study. AMOS 28 was employed for confirmatory factor analysis (CFA) to examine the measurement model for all the constructs in our research. SPSS 28 was used to do Pearson correlation, common method bias, descriptive statistics, and PROCESS (the plug-in) by Hayes.

Consistent with Hayes [84]; PROCESS macro (Model 4) and (Model 59) were chosen to examine the mediation model and the moderated mediation model, respectively. A 5000 bootstrap resample with 95% confidence intervals (CIs) indicates whether or not the effects in the selected Model 4 and Model 59 are significant [84]. That is, where 95% CIs exclude zero, a significant effect is established. Before the data analyses, all the constructs in the study were standardized in Model 4 and Model 59.

4. Results

4.1. Common Method Variance (CMV). In order to prevent the presence of CMV, we adhere to the two common method biases frequently utilized in supply chain management research [1]: process control and Harman's one single factor test. While collecting data through a questionnaire survey, we adhere to the principles of confidentiality and anonymity, and the data gathered will be used for academic research purposes only. The Harman's single factor results indicate the first factor accounted for 38.18%. This is less than the critical criterion of 50%, which means that CMB is not a big problem in the research being done [85].

Additionally, the aforementioned test was supplemented with a test for collinearity. Variance inflation factor (VIF) estimates regarding correlation among the constructs in this study were below the recommended cutoff of 3.3 [86]. Hence, the result is not clouded by multicollinearity issues [87].

4.2. Measurement Model. To check whether the data collected followed normal distribution, Lei and Lomax [88] suggested that (skewness $< |2|$ and kurtosis $< |3|$; as demonstrated in Table 2, skewness lies inside the cut-off range (0.023 and 0.641) and kurtosis lies inside the cut-off range (0.409 and 1.515), indicating that the data collected can be said to be normally distributed.

All measurement items were tested for validity and reliability. The results revealed that every factor loading was greater than 0.6. The AVE of each variable was estimated to satisfy convergent validity [89]. The recommended lower limit of 0.5 for AVE [90]. Construct reliability (CR) estimates were made for each construct in order to examine composite reliability. 0.7 should be the lower limit [91]. The factor loadings (0.631 to 0.884), CR (0.833 to 0.958), and (0.549 to 0.838) as outlined in Table 3 Therefore, the items are appropriate, and the constructs are consistent and reliable.

To estimate discriminant validity, Fornell and Larcker [89] indicated that the square root of each AVE should be larger than the surrounding correlations. Table 4 demonstrates that the square root of AVEs (in parenthesis, in bold) is found to be larger than the surrounding correlations, demonstrating evidence of discriminant validity.

The research model's CFA is shown in Table 5. We estimated the model fit indices by various statistics: TLI, IFI, NFI, CFI, and RMSEA. NFI, TLI, and IFI values should be greater than 0.8; CFI values should be greater than 0.9; and RMSEA values should be less than 0.08 [92]. The results showed that all of them fell within the acceptable limits, which means that our chosen model fits the data well.

4.3. Mediation Model. It was hypothesized that green supply chain collaboration would mediate the relationship between BDA, AI, and EP in hypothesis 4. To validate this hypothesis, the current research followed a 4-step process for evaluating the mediation effect [93]. The 4-step process was as follows: (1) a significant relationship between BDA-AI and EP; (2) a significant relationship between BDA-AI and GSCC; (3) a significant relationship between GSCC and EP after controlling for BDA-AI; and (4) a significant coefficient for the indirect path between BDA-AI and EP via GSCC. The bias-corrected percentile bootstrap approach was adopted to determine if the last process was fulfilled. Also, as covariates,

Table 1: Previous studies' findings associated with the constructs of this study.

Authors	Constructs examined	Findings
Dubey et al. [7]	Big data analytics and artificial intelligence, operational performance, entrepreneurial orientation, and environmental dynamism	The study reported that manufacturing firms that are entrepreneurially oriented have the potential to use digital technologies such as BDA-AI to enhance their decision-making capabilities, which can further promote operational performance. It was also reported that the positive impact of entrepreneurial orientation on operational performance is less pronounced in more dynamic environments
Kitsis and Chen [25]	Stakeholder pressures, green supply chain practices, and top management commitment	The study reported significant empirical support for the relationship between stakeholder pressures and top management commitment. The study further suggested that stakeholder pressure can promote top management's commitment and efforts to undertake green operations
Benzidia et. al. [6]	Big data analytics and artificial intelligence, green supply chain integration, and hospital environmental performance	The study reported that the use of BDA-AI has a significant positive effect on green supply chain collaboration in the hospital sector. It was suggested that the application of BDA-AI can promote better collaboration between supply chain stakeholders. It was also suggested that the use of BDA-AI systems enable managers to put in place new methods in real-time to enable them to visualize and comprehend knowledge on environmental initiatives
	Big data analytics-artificial intelligence, green supply chain collaboration, top management commitment, and environmental performance	The current study found a significant positive relationship between BDA-AI and EP. Green supply chain collaboration was found to play a mediating role between BDA-AI and EP. Our findings also revealed that the positive impact of BDA-AI on GSCC is further enhanced by the level of top management commitment and that the positive impact of BDA-AI on EP is dampened when the level of top management commitment is low. Our findings provide important practical implications for managers in the manufacturing industry seeking to explore and implement BDA-AI in their environmental efforts. They should intensify TMC to develop efficient green supply chain collaborative efforts that enhance environmental performance

Table 2: Participant characteristics.

Demographic information ($n = 402$)	Frequency	%
Gender		
Male	341	84.90
Female	61	15.10
Education		
Bachelor	106	26.40
Master	132	32.80
Doctorate	42	10.40
Others	122	30.30
Firm size (number of employees)		
Less than 20	58	14.40
21–40	102	25.40
41–60	108	26.90
61–80	63	15.70
Above 81	71	17.70
Business type		
Chemical	68	16.90
Machinery and industrial equipment	110	27.40
Food/Consumer goods	113	28.10
Pulp and paper	55	13.70
Automotive components	56	13.90
Tenure (years)		
Less than 5	27	6.70
6–10	59	14.70
11–15	128	31.80
Above 15	188	46.80

Table 3: Measurement model.

Construct	Items	SFL	Distribution (normal)	
		(λ)	Skewness	Kurtosis
Big data analytics-artificial intelligence	∝ = 0.866			
	CR = 0.869 AVE = 0.609			
	BDAA1	0.822	0.061	−1.404
	BDAA2	0.789	0.163	−1.515
	BDAA3	0.772	−0.040	−1.461
	BDAA4	0.702	−0.112	−1.306
Green supply chain collaboration	∝ = 0.928			
	CR = 0.895 AVE = 0.838			
	GSC1	0.803	0.343	−1.245
	GSC2	0.866	0.221	−1.217
	GSC3	0.841	0.281	−1.219
	GSC4	0.852	0.480	−1.088
Top management commitment	∝ = 0.847; CR = 0.864; AVE = 0.763			
	TMC1	0.843	0.517	−0.409
	TMC2	0.880	0.255	−1.099
	TMC3	0.884	0.302	−1.009
	TMC4	0.874	0.341	−1.082
	TMC5	0.881	0.352	−1.098
Environmental performance	∝ = 0.829; CR = 0.811; AVE = 0.549			
	EP1	0.740	−0.023	−1.264
	EP2	0.712	0.183	−1.401
	EP3	0.631	0.642	−0.705
	EP4	0.739	0.308	−1.118
	EP5	0.783	0.515	−1.018
	EP6	0.701	0.209	−1.016

Note: (1) BDAA = big data analytics-artificial intelligence; GSC = green supply chain collaboration; TMC = top management commitment; EP = ; environmental performance; (2) λ = standard factor loading; AVE = average variance extracted; CR = composite reliability; ∝ = cronbach alpha.

Table 4: Descriptive statistics, correlation analysis and discriminant validity.

Construct	M	SD	BDAA	GSC	TMC	EP	Education	Firm size	Firm age	Tenure
BDAA	3.805	1.012	**0.780**							
GSC	3.717	0.998	0.501**	**0.914**						
TMC	2.001	0.669	0.619**	0.622**	**0.873**					
EP	3.980	1.271	0.488**	0.531**	0.562**	**0.740**				
Education	3.127	0.821	0.581**	0.599**	0.588**	0.517**	—			
Firm size	3.101	0.802	0.504**	0.631**	0.503**	0.600**	0.157**	—		
Firm age	3.364	0.911	0.526**	0.657**	0.481**	0.513**	0.022**	0.109**	—	
Tenure	2.662	0.727	0.472**	0.516**	0.499**	0.524**	0.265**	0.029**	0.029**	—

Note: (a) M = mean, SD = standard deviation; (b) correlations (two-tailed) were significant at $^{**}p < 0.01$; (c) boldface indicates that the square root of AVEs is larger than the off-diagonal (nearby) correlations.

Table 5: Model fit estimate.

Goodness of fit index	CMIN/df (<3)	IFI (>0.9)	CFI (>0.9)	NFI (>0.9)	RMR (>0.9)	TLI (>0.9)	RMSEA (<0.08)
	564.183/284 = 1.987	0.966	0.959	0.961	0.119	0.940	0.050

education, firm size, firm age, and tenure were added to the analyses that were just talked about.

As illustrated in Table 6, in Model 1, the results indicated that big data analytics and artificial intelligence significantly and positively predicted environmental performance ($\beta = 0.299$; $p < 0.001$). In Model 2, the second step results indicated that BDA-AI is a significant and positive predictor of green supply chain collaboration ($\beta = 0.504$; $p < 0.001$). In Model 3, after controlling for BDA-AI, GSCC was revealed to be a significant and positive predictor of environmental performance ($\beta = 0.305$, $p < 0.001$). Finally, the results for bias-corrected percentile bootstrap for indirect effect of BDA-AI on environmental performance through GSCC were significant ($\beta = 0.149$, SE = 0.018, CIs 95% = [0.106, 0.264] confidence interval excludes zero as shown in Table 7. Therefore, hypotheses 1, 2, 3, and 4 (mediation effect) were all validated.

4.4. Testing for Moderation Model. Model 59 in Hayes' PROCESS macro assumes that the moderator affects all three paths of the mediated model, which is consistent with our study's conceptual model. To explore the moderating role of top management commitment in the relationship between BDA-AI and GSCC (hypothesis 5), BDA-AI and EP (hypothesis 6), and GSCC and EP (Hypothesis 7), Model 59 of the PROCESS macro was used.

Our research examines the moderating effect of top management commitment on (a) the association between BDA-AI and GSCC (Model 1 of Table 8); (b) the association between BDA-AI and EP (Model 2 of Table 8); and (c) the relationship between GSCC and EP (Model 2 of Table 8). Similar to the mediation analysis in the previous section, education, firm size, firm age, and tenure were added as covariates. Consistent with Hayes [84]; a moderated mediation model will be established should one or both of the following paths be supported: (a) the path between BDA-AI and GSCC was moderated by top management commitment; or (b) the path between GSCC and EP was moderated by top management commitment.

As illustrated in Model 1 of Table 8, the results indicated that the main effect of BDA-AI on GSCC was statistically significant ($\beta = 0.120$, $p < 0.001$) and that this effect was moderated by top management commitment ($\beta = 0.017$, $p < 0.05$) with a 95% CI of [0.088, 0.141], implying that top management commitment moderated the positive relationship between BDA-AI and GSCC, validating hypothesis 5. Consequently, as illustrated in Model 2 of Table 8, the main effect of BDA-AI on EP was statistically significant ($\beta = 0.221$, $p \leq 0.001$) but this effect was moderated by top management commitment ($\beta = 0.078$, $p \leq 0.05$) with a 95% CI of [0.103, 0.152] validating hypothesis 6. Finally, still in Model 2 of Table 7, there was a significant main effect of GSCC and EP ($\beta = 0.113$, $p < 0.001$), but this particular effect was not moderated by top management commitment ($\beta = 0.059$, $p > 0.05$) with a 95% CI of [−0.064, 0.125] implying that top management commitment did not moderate the positive relationship between GSCC and EP, rejecting hypothesis 7.

The two significant effects of the interactions were further examined via simple slope analysis. For hypothesis 5, interactions were plotted at +1 and −1 SD from the mean of top management commitment (see Figure 2). For both high and low levels of top management commitment, we created a simple slope to assess the strength of the relationship between BDA-AI and GSCC. The result of the conditional direct effect of BDA-AI on GSCC showed that the strength of the positive relationship is stronger for higher levels of top management ($\beta = 0.194$, $t = 3.272$, $p \leq 0.001$), while the relationship is weaker ($\beta = 0.061$, $t = 1.612$, $p \leq 0.001$) at lower levels of top management commitment to strategic performance. Therefore, further supporting hypothesis 5.

For hypothesis 6, +1 and −1 SD from the mean of top management commitment were used to plot the interactions (see Figure 3). For both high and low levels of top

Table 6: Direct and mediation effects GSCC partially mediated the relationship between BDA-AI and environmental performance (PROCESS model 4, CI = 95%).

Predictor	Model 1 (EP)		Model 2 (GSC)		Model 3 (EP)	
	B	*t*	*B*	*t*	*B*	*t*
BDAA	0.299	5.998***	0.504	10.104***	0.305	4.694***
GSC					0.184	4.981***
Education	0.018	0.611	0.050	1.168	0.029	1.117
Firm size	0.039	1.302	0.020	0.700	0.041	1.027
Firm age	0.021	1.001	0.011	0.521	0.023	1.099
Tenure	0.026	1.102	0.012	0.223	0.024	1.042
R^2	0.155		0.187		1.938	
F	11.224***		19.991***		13.557***	

Note: (1) each column demonstrates a regression model that predicts the criterion at the column's top; (2) *** $p < 0.001$.

Table 7: Bootstrap results for the indirect effect (indirect effect of BDA-AI on EP via GSCC).

Bootstrap resamples = 5000	*B*	SE	LLCI	ULCI
The indirect effect of (BDA-AI ion EP via GSCC)	0.149	0.018	0.106	0.264

Table 8: Testing for moderated mediation: top management commitment moderates the direct and indirect relationship between BDA-AI and environmental performance (PROCESS model = 59, CI = 95%).

	Bootstrapped CI 95%						
	B	SE	*t*	*p*	LLCI	LLCI	R^2
Model 1: Mediator variable model	Outcome: green supply chain collaboration						
Big data analytic-artificial intelligence	0.120	0.024	4.911	≤0.001	0.103	0.209	0.806
Top management commitment	0.799	0.021	30.228	≤0.001	0.802	0.913	
Big data analytic-artificial intelligence *X* top management commitment (interaction)	0.017	0.019	1.995	0.012	0.088	0.141	
Co: education	−0.019	0.020	−1.221	0.173	−0.071	0.052	
Co: firm size	−0.009	0.010	−0.097	0.863	−0.026	0.025	
Co: firm age	0.022	0.011	2.003	0.027	0.010	0.062	
Co: tenure	−0.008	0.015	−0.501	0.707	−0.064	0.018	
The conditional direct effect of BDA-AI on GSCC							
Top management commitment (-1SD)	0.061	0.099	1.612	≤0.001	0.094	0.180	
Top management commitment (+1SD)	0.194	0.044	3.272	≤0.001	0.181	0.303	
Model 2: Dependent variable model dependent: environmental performance							
Big data analytic-artificial intelligence	0.221	0.051	4.642	≤0.001	0.127	0.318	0.228
Green supply chain collaboration	0.113	0.042	3.928	≤0.001	0.201	0.494	
Top management commitment	0.195	0.082	2.531	0.012	0.134	0.312	
Big data analytic-artificial intelligence *X* top management commitment (Interaction)	0.078	0.032	2.244	0.028	0.103	0.152	
Green supply chain collaboration *X* top management commitment (Interaction)	0.059	0.037	0.726	0.311	−0.064	0.125	
Co: education	−0.028	−0.033	−1.010	0.355	−0.092	0.0	
Co: firm size	−0.041	0.022	−1.492	0.119	−0.088	0.010	
Co: firm age	0.019	0.014	0.699	0.436	−0.024	0.049	
Co: tenure	0.021	0.032	−0.591	0.493	−0.114	0.088	
The conditional direct effect of BDA-AI on environmental performance							
Top management commitment (-1SD)	0.089	0.058	1.611	0.023	0.094	0.144	
Top management commitment (+1SD)	0.311	0.069	4.649	≤0.001	0.292	0.466	

Note: $n = 402$; B = unstandardized regression coefficients; bootstrapping resample size = 5000; LLCI = confidence interval (lower level); ULCI = confidence interval (upper level).

management commitment, we created a simple slope to assess the strength of the positive relationship between BDA-AI and EP. The result of the conditional direct effect demonstrated that the association is weaker ($\beta = 0.089$, $t = 1.611$, $p < 0.05$) when top management commitment is low, while the association is stronger ($\beta = 0.311$, $t = 4.649$, $p < 0.001$) at high levels of top management commitment. Therefore, further validating hypothesis 6.

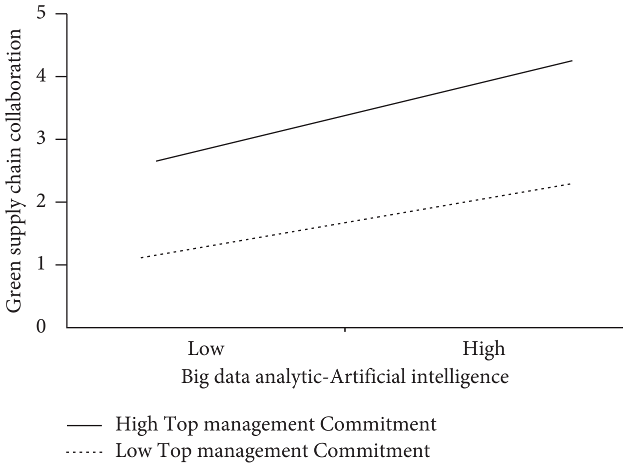

Figure 2: The moderating effects at different levels of TMC on the relationship between BDA-AI and GSCC.

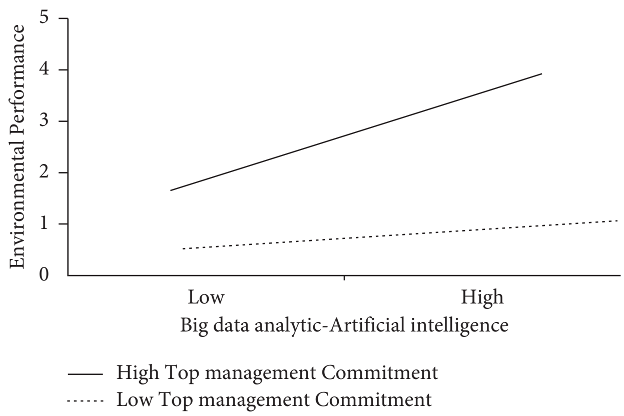

Figure 3: The moderating effects at different levels of TMC on the relationship between BDA-AI and EP.

5. Discussion

The current research examined a moderated mediation model based on a Turkish sample and uncovered the underlying mechanisms in the association between BDA-AI and environmental performance in the context of the Turkish manufacturing sector. First, it was revealed that BDA-AI-empowered decisions have a positive impact on EP. This particular result provides empirical evidence for the arguments of Chiarini [94]; Dubey et al. [45]; and Raut et al. [47]; who argued that the BDA-AI in the context of green supply chain management can promote EP. The observation here is that the use of new technologies such as BDA-AI in the manufacturing sector can suppress information asynchronization in the supply chain and manage complex environmental data with the aim of improving environmental performance. Second, it was discovered that BDA-AI-empowered decisions are a determinant of GSCC. This result aligns with the recent findings of Benzidia et al. [6] and the conclusions of Liu et al. [48]; Singh et al. [49]; and Raut et al. [47]. The discovery of BDA-AI as a determinant of GSCC indicates that such a relationship is not exclusive to the western context only. The consistency of this pattern of results could imply that the manufacturing sector needs to establish supporting IT infrastructure, such as BDA-AI, to develop collaborative relationships for green supply chain operations. Third, GSCC was discovered to have a positive impact on EP. This result confirms the findings of Benzidia et al. [6] and Seman et al. [60]; who reported that green supply chain collaboration leads to enhanced environmental performance. Clearly, manufacturing firms should collaborate with their suppliers to attain improved green performance. Fourth, it was discovered that GSCC mediated the direct relationship between BDA-AI and EP.

Fifth, top management commitment moderates the relationship between BDA-AI and GSCC, such that the positive relationship is stronger for higher than lower levels of top management commitment. Sixth, TMC moderates the relationship between BDA-AI and environmental performance so that when top management commitment is low, the strength of the positive relationship is less.

Lastly, the role of TMC as a moderator in the link between GSCC and EP was not supported by our results.

5.1. Theoretical Implication. The current study developed and empirically examined a research framework that demonstrates how BDA-AI technology enhances environmental performance. Our research provided empirical evidence that using innovative technologies (e.g., BDA-AI) for decision making promotes the information processing capabilities of manufacturing firms. The finding backs up our belief that manufacturing firms with advanced technological infrastructure and smart analytical capacity can improve their environmental performance. This extends organizational information processing theory (OIPT) to the Turkish manufacturing industry, which has not gotten much attention.

The current study also demonstrates how integrating innovative technologies such as BDA-AI enables GSCC and further promotes green operations. However, the relationship between BDA-AI and GSCC has not been empirically proven in the context of Turkish manufacturing firms. Further, the manufacturing industry is made up of various parties with varying desires; thus, making decisions requires consensus among stakeholders who share the philosophy of a circular economy [95]. Particularly, the OIPT emphasizes the synchronization of information processing capacities at both intra-organizational and cross-organizational levels in order to promote environmental performance. Therefore, the current study offers a novel contribution on how the application of BDA-AI technological systems impacts GSCC in the manufacturing industry. This current study also offers important knowledge on how GSCC impacts EP.

The current study also provides new evidence and reveals green supply chain collaboration as an important mechanism in the association between BDA-AI and environmental performance. Our study shows how this mechanism is involved in the process of enhancing the environmental performance of manufacturing firms, moving from the use of advanced technologies with information processing capabilities (BDA-AI) through GSCC to achieving environmental performance. This result could mean that manufacturing companies that use BDA-AI to handle out-of-sync information and complicated data about the environment are more likely to work with their suppliers and improve their green operations.

Furthermore, a key finding that has not been reported in the existing literature is that the current study provides new evidence on how TMC moderates the association between BDA-AI and EP. Contrary to previous studies that explored top management commitment as a predictor (Bag et al., 2020) or as a mediator [25], our study examined top management commitment as a moderator. To our knowledge, our study was the initial study that investigated the role of TMC in the relationship between BDA-AI and EP, revealing that TMC moderates the relationship between BDA-AI and green supply chain collaboration, such that the positive relationship is stronger for higher than lower levels of top management commitment, and that TMC moderates the relationship between BDA-AI and EP, such that the strength of the positive relationship is reduced for lower levels of top management commitment. A more logical explanation would be that top management support is necessary for successful green initiative operations. Thus, top management actions are critical in laying the groundwork for green operations. This pattern of results aligns with extant literature that indicates that green operations are majorly influenced by the choices of top management [96]. So, the current research adds a lot to what we already know by using a new method that goes beyond the direct link between BDA-AI and environmental performance and takes into account how complicated real life is.

5.2. Practical Implications. The research offers important practical implications that the manufacturing industry should be aware of, especially policy makers. First, there is a chance for policy makers in the manufacturing industry to take advantage of BDA-AI's technological capabilities to implement an ardent environmental policy that covers the entire operations of the manufacturing supply chain. Precisely, decision makers can administer new indicators and measures in real time by using BDA-AI technologies, which can help improve visualization and comprehend information on environmental initiatives.

Second, our findings suggest that GSCC is a crucial element in the manufacturing industry. Therefore, organizations' leaders should not only depend on the use of IT infrastructure to implement green initiatives but also collaborate with suppliers within the supply chain if they are to meaningfully contribute to a cleaner environment and a better society.

Third, our findings also suggest that manufacturing firms cannot succeed in the present era of big data if they only have access to good data and effective information processing; a strong top management commitment to sustainable initiatives can intensify communication and collaboration with the suppliers and enhance the establishment of shared beliefs and actions for green operations. Therefore, TMC is a crucial driver of green operations and EP. But the current study wants to add that organizations' leaders should pay enough attention to TMC and understand how different levels of top management commitment can affect BDA-AI on GSCC and, as a result, environmental performance.

Finally, the findings of this study indicate that the positive impact of BDA-AI on GSCC is further enhanced by the level of top management commitment. Hence, manufacturers' decision-makers seeking to explore and implement BDA-AI in their environmental initiatives should intensify TMC to develop efficient green supply chain collaborative efforts that promote environmental performance.

6. Conclusion

The empirical findings of the current study provide a more nuanced understanding of the use of BDA-AI technology in achieving environmental performance, which in turn helps to clarify the role green supply chain collaboration and, most importantly, top management commitment play in these relationships. So, the data-driven research we did for this study offers more benefits by giving business leaders who agree with our suggestions more information they can use to evaluate how well they are being put into practice.

To the best of our knowledge, based on OIPT, the current research is the first academic effort to demonstrate the relationships between the application of BDA-AI through GSCC and enhanced environmental performance in the context of the Turkish manufacturing industry. In general, our study adds to the small but growing amount of information about how BDA-AI systems can be used in a circular economy.

7. Limitations and Future Research Directions

The current study offers important contributions, but it also has some limitations that may open up a new research direction. First, because the sample was limited to the manufacturing industry in Turkey, our conclusions may not apply to other nations' supply chains depending on their technological capabilities and national cultures that support sustainability. Future studies could examine manufacturing firms in other developing nations to complement and solidify our findings. Second, though this research has demonstrated the crucial role of green supply chain collaboration as a mediator in the link between BDA-AI and EP, future research examining the moderating effect of green supply chain collaboration could yield more useful insights. Could it be that, for example, when GSCC is high, the relationship between BDA-AI and EP is stronger? Third, future studies could also look into other constructs, such as stakeholder pressure in the abovementioned relationships. Fourth, we urge future studies to validate the empirical results from our study using a larger sample size, as well as in other sectors and nations. Finally, there still exists a sparse body of knowledge or information regarding the application of BDA-AI in attaining improved environmental performance; more study should be carried out to promote its effectiveness in green operations.

Data Availability

The data used to support the findings of this study are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Designing a Policy-Making Model for Biomass Energy Development Training in the Agricultural Supply Chain Sector

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This basic-applied and hybrid survey aimed to design and validate a policy-making model for biomass energy development training in the agricultural supply chain sector. Creating a supply chain for basic agricultural products by including a wide range of agricultural subsectors from the supply of required production inputs to the final consumer's access to the goods will lead to an increase in the productivity of the agricultural sector as well as the upstream and downstream industries related to it. Therefore, considering the importance of creating an optimal supply chain for various agricultural products, in this study, the situation of the supply chain of agricultural products in the country has been examined. Considering that the lack of appropriate policies regarding the management of the supply chain of agricultural products can lead to the inefficiency of the supply chain of agricultural products in various stages including supply of inputs, production and distribution, and marketing of products, it is suggested that planning and related policies should be implemented in order to improve the infrastructure that leads to increasing the efficiency of some logistics subsystems such as transportation, warehousing, communication, and information systems. Purposive sampling was used in the qualitative part, and stratified random sampling was utilized in the quantitative part. The data were collected by reviewing resources and interviewing ten experts, who were mainly policy-making managers of biomass energy development training and academic researchers. The interviews continued until reaching theoretical saturation, and the samples of the quantitative part included 384 members of the environmental and agricultural Jihad employees, who were selected based on Cochran's formula. The effective components of the education policy of biomass energy development and their factors were identified by the exploratory method and evaluated through descriptive-survey research. The validity and reliability of the components were examined, and Cronbach's alpha of all components was higher than 0.7. The essential components of the effective factors were measured in the education policy of biomass energy development in the agricultural sector. The model validity was verified through the structural equation method, and the selection of concepts, dimensions, and indicators was highly accurate and could provide a suitable framework for developing a policy perspective document for biomass energy education. According to the coding results, the development and acceptance of biomass energy systems by the Ministry of Agriculture Jihad and Environment in the country is unsuitable and sustainable, considering the passage of more than a decade of designing and implementing plans. According to experts, some farmers implement this method in their fields for one or two years and return to traditional methods after accepting this technology. The main achievements are as a core category or phenomenon conditions to casual conditions path with coefficient 0.916 is significant. Strategies to the core category or phenomenon conditions' path with a coefficient of 0.051 are significant. Strategies to contextual conditions' path with coefficients 1.231 are significant. Strategies for intervening condition path with coefficients 2.235 are significant. Consequences to strategies' path with coefficients 0.807 are significant. Therefore, the development of biomass energy is an inevitable necessity, considering the erosion and reduction of soil organic matter, increasing energy costs, and other factors.

1. Introduction

Biomass includes all biodegradable components of products, sewage, and agricultural waste, including plant and animal, as well as forest industries, sewage, and urban and industrial waste. The use of energy in biomass helps reduce waste in the agricultural sector [1]. A huge amount of biomass in Iran is burned or left unused by traditional methods with low efficiency, including rapeseed residues, cotton residues, and olive residues after oiling. Using these biomasses with the gasification technology and conversion of various biomass into combustible gases (synthesis gas) can reduce the need for fossil fuels and save energy costs [2]. Fossil fuels such as oil and its derivatives cause countless environmental pollution as they are nonrenewable resources and are costly. As a result of fossil fuels, toxic gases enter the environment and make it difficult for humans and animals to breathe [3, 4].

On the other hand, the concentration of these gases in the Earth's atmosphere prevents heat from escaping from the Earth and increases the air temperature and causes extensive climate changes and the greenhouse effect [5]. Therefore, experts are looking for an alternative clean, renewable source of energy such as biomass to avoid these risks. The perishability of fossil fuels, diversification of energy sources, sustainable development and energy security, and the clean and renewable nature of new energy resources such as biomass have attracted global attention to their use and increased their share in the global energy portfolio [6]. Therefore, a special role has been assigned to renewable energy sources in international programs and policies, including United Nations programs, but the compatibility of these energy resources with the current global energy system is still complicated [7, 8]. The activities and expenditure of government and company budgets for developing biomass energy reduce the cost of renewable energy and compete with existing traditional systems [9, 10]. These biomass resources can provide for the needs of different parts of human society as the main form of energy such as electricity or energy carriers such as gaseous and liquid fuels [11, 12]. So far, no research studies with this title have been conducted in Iran. The strategic document and roadmap for the development of technologies related to biomass energy are inspired by the twenty-year vision document. The system orientation section (c) of this document mentioned the support of the strategic council of experts in the country's biomass sector and the guidance of research and development activities, evaluation, monitoring, and updating of the activities (2015). The new energy department in the Renewable Energy and Energy Efficiency Organization (REEEO) refers to the measurement, capacity, and Atlas preparation for renewable energy sources, including biomass (2013).

Article 148 of the fifth agricultural sector development program emphasizes the replacement of nonfossil and renewable fuels with wood fuels (2010). The analysis of the current situation of educational programs in the agricultural sector and the presentation of a suitable model that was carried out by the Imam Khomeini Higher Education Center in the second collection of articles of scientific lectures (2010) shows that no research studies on this title have been carried out so far in Iran. This study was conducted considering the importance of educational programs in improving the skill level and awareness of people in the field of improving and developing biomass energy. The comprehensive model of educational policies regarding the duties of the Ministry of Agricultural Jihad in developing biomass energy according to the needs of education in the upstream documents, including the five-year development plans, was included in the sixth development plan in Section 7, Article 31, Clause D and Section 9, Article 38, Clauses Z and F. (2017). The country's comprehensive energy planning strategic document is mentioned in the vision statement and model presentation sections such as MESSAGE, LEAP, NEMS, and TIMES (2016). According to experts, the compilation and validation of this model and its adaptation to standards such as ISO 50001 reduced the emission of greenhouse gases and other environmental consequences. This model ensures energy cost reduction through systematic energy management at a high level of device compliance with ISO 9001 (quality management) and ISO 1401 (environmental management) standards, which are based on the Deming cycle (PDCA) (2018).

Effective training in biomass energy development at the ministry level requires new thinking, models, approaches, tools, and mechanisms. Designing and validating a comprehensive and standardized model for training people related to developing biomass energy improves the organization at the national and international levels and increases productivity and subsequent positive results and consequences. Therefore, designing a comprehensive model according to the following damages and discussing biomass education in the Ministry of Agriculture Jihad is necessary. The reasons for conducting this research are the lack of appropriate administrative structures, the motivation for short-term courses, and the desire to participate in long-term courses, and the harms related to laws and regulations, including the lack of continuous review of laws related to education and lack of attention. It is enough to train in development programs. In addition, the lack of forecasting of executive mechanisms to achieve the education goals and executive guarantees and protective regulations, damages related to creating systems, lack of clarity about the system design and connection between the education system and other personnel systems, and damages related to the biomass energy development training process were effective. The lack of optimal attention to need assessment and codified model, the absence of attention to the mechanisms of program design validation, and creating policy-making models for biomass energy development training in Iran's agricultural sector were the other reasons.

According to the above-mentioned points, the main questions that were considered in this paper are as follows:

Q1- What are the components and subcomponents of biomass energy development education in the agricultural sector?

Q2- What is the current status of biomass energy development training in Iran's agricultural sector?

Q3- What is the appropriate model for the policy-making of biomass energy development education in Iran's agricultural sector?

Q4- What is the credibility of the proposed policy model for biomass energy development education in the agricultural sector?

In response to the above-mentioned questions, the main contributions of this study are as follows:

(i) Designing and explaining the policy model of biomass energy development education in the agricultural sector
(ii) Identifying the policy components and subcomponents of biomass energy development education in Iran's agricultural sector
(iii) Determining the current policy status of biomass energy development training in the Ministry of Agriculture with regard to the components and subcomponents
(iv) Providing a suitable educational model according to the country's high-level documents
(v) Determining the degree of appropriateness (validation) of the proposed model

The rest of the article is organized as follows: Section 2 presents a literature review. Section 3presents research methodology. Section 4 presents research findings. Section 5 presents managerial insights and implications. Finally, Section 6 presents an overall conclusion and suggestion for future studies.

2. Research Literature

2.1. Related Survey Work. Rhofita et al. [13] presented a method to assess the energy production from biomass residue as a primary consideration in its development. Statistical data and field observations have been used to estimate the total availability of residue. Furthermore, to calculate the energy potential of biomass residue, the minimum and maximum value parameters, such as residue-to-product ratio, moisture content, and heating value, were obtained from works of literature. The power potential was also analyzed through three scenarios of the conversion factor efficiency, i.e., low, medium, and high, to provide comprehensive results. Lee et al. [14] discussed the technical and economic analysis of the biomass supply chain. Due to the increasing risk of climate change and the reduction of nonrenewable energy resources, countries around the world are looking for diversification in their energy profile, whereby biomass is one of the attractive options for energy production from raw materials. A comprehensive technical and economic analysis should be performed to attract more interest and investment from industry players in biomass-based industries. In addition, various uncertainties related to the supply chain, including biomass availability, demand changes, and material price fluctuations, should be considered in the evaluation to provide a more accurate and reliable feasibility estimate. The purpose of this review article is to (a) provide an overview of the different types of methods or approaches used in assessing the feasibility of biomass-based industries from a technical-economic point of view and (b) describe the uncertainties of the supply chain that must be used. A Malaysian case study is included to illustrate the impact of this uncertainty in the evaluation model. Apart from that, some uncertainties and unassessable risks are critically examined in this paper. It was found that 78% of the reviewed articles choose the mathematical modeling evaluation method, and majority of them are inclined towards mathematical modeling with optimization (i.e., deterministic and stochastic optimization). Furthermore, only a minority have conducted stochastic evaluations that incorporate the uncertainty of the biomass supply chain. This review discusses six measurable uncertainties. Avcioğlu et al. [10] evaluated the energy potential of agricultural biomass residues in Turkey from information on the characteristics of agricultural biomass residues from 16 EU countries, as well as in India, Cameroon, China, Pakistan, Nigeria, Uganda, and Turkey. Some properties such as the residual crop ratio, moisture level, and lesser amounts of heating calorific dry matter value were considered. In addition, a mathematical model is defined to calculate the residual energy potential of Turkish agricultural biomass. Oh and Park [14] investigated the use of agricultural products as a new biological resource using a mass reduction model to optimize the braking (drying) of biomass through the conversion of products into fuel through the breaking process. Pepper stalk was chosen as a renewable agricultural product for this energy conversion process. Longer retention time and higher temperature and higher mass reduction and higher heating value by inflation showed a correlation between heating value and mass reduction. Calorimetric analysis was performed to obtain the frequency factors and biomass activation energy at different heating rates. The experimental results were in good agreement with the simulated results with the rate of temperature increasing inside the biomass. Aberilla et al. [16] showed that providing energy in general from residual biomass in small farming communities significantly reduces environmental impacts while improving waste management practices. Morato et al. [17] studied the potential of energy production from agricultural residues in Bolivia and concluded that biomass energy could meet the energy needs of 58% of the population, indicating the vast potential of Bolivia to replace fossil fuels with residual biomass in energy production. Bilandzija et al. [18] investigated the energy potential of solid agricultural biomass in Croatia. In 2017, International Finance Corporation's Biomass to Energy Guide for Developers and Investors benefited from a wide range of materials from industry, government, and nongovernmental experts. Wang et al. [19] analyzed the temporal and spatial changes in agricultural biomass and its policy implications as alternative energy in Northeast China-Cyprus using statistical data, simulation modeling, and a dynamic analysis framework for the potential and distribution of regional agricultural biomass in Heilongjiang, China. Gray correlation analysis showed that precipitation, total population, mechanical power, and agricultural planting greatly influenced biomass resources. This study proposed to create a platform for the management and planning of scientific resources to achieve dynamic allocation and planning of agricultural biomass that improves the sustainability of resources. The methods used in this research can be applied to other regions, and it can provide basic data for local authorities to consider a strategy for planning and developing biotechnology. Jahantigh [20] found that it is possible to produce combustible gas and electricity and reduce waste in the agricultural sector by using biomass-to-gas conversion devices. Liquid fuels and chemical fertilizers can also be produced from the output of this device. Sofi et al. (2015) showed that the increase in the price of fossil fuels in Iran could provide the basis for developing renewable systems. Faraji et al. [21] compared several common educational models to examine their strengths and weaknesses and provided the possibility to choose the most comprehensive method for exploitation, stated the effectiveness of the ISO 10015 educational standard as the most comprehensive education system, and provided some effective suggestions for using this standard. Makari et al. [6] prioritized factors based on predetermined indicators using the AHP method and Expert Choice software, and finally, the financial factor was recognized as the most important factor in biomass development. This prioritization can help make important and basic decisions in this area and achieve a successful program for developing biomass energy with rice waste in the province, causing economic prosperity and optimal use of this waste. Mahmoudi Jolfan [22] indicated that environmental education is effective when it targets and intelligently focuses on private-sector investors and public-sector policymakers. Safari and Salimi Valik Bani [23] examined the agricultural biomass gasification methods to produce hydrogen, which has the highest combustion energy among fuels, as a clean energy carrier. Vavrova et al. [24] modeled the biomass potential of agricultural land for energy using high-resolution spatial data regarding food security scenarios to provide national food security strategies. The biomass potential was modeled using the main algorithms allowing compliance with several constraints in nature and soil protection and competition of crops for land. Modeling also showed that biomass potential is nonlinearly dependent on land allocated for energy crops. The analysis results confirmed that the remaining biomass as an energy source in the Czech Republic has a good potential to be used for planning the sustainable development of biomedicine. Babak and Madhoshi [25] pointed out that reducing fossil fuels and increasing energy demand, as well as the rapid growth of population and urbanization and the use of conventional energy sources such as coal, oil, and natural gas, which is on the verge of extinction, has caused attention to biomass, renewable resources, and fuel production, thus turning it into a logical choice to replace oil. Therefore, it is necessary to investigate renewable fuel characteristics and production processes from agricultural waste. Vahidi and Mehnani [23] studied the awareness level of university graduates employed in the oil industry. Rahimi et al. [27] expressed the output of some innovations in the field of renewable energy, including knowledge, policy engineering, and educational techniques of renewable energy, to examine the current education state on this type of energy in Iran and make a comparative comparison with this type of education in Australia, as one of the leading countries and a model in this field. Lucia [28] reviewed the knowledge connection between biomass and bioenergy. Irji Rad [29] examined the current and optimal status of the Ministry of Agriculture Jihad educational programs, and the average status was lower than optimal in all components and subcomponents. Eight final components were extracted by implementing factor analysis, and the proposed model was developed by implementing multivariate regression. Asadi et al. [26] investigated practical solutions for the wider use of some energy from biomass and showed that biofuels, especially biodiesel, have been proposed as an alternative fuel in Europe. In addition, Brown and Quintana [27] examined biofuels for reducing waste in 9th–12th grade students for the National Renewable Energy Laboratory, to provide a curriculum on the production of biofuels based on the content standards of national science education. In this curriculum, the concept of alternative fuels is first introduced to the students, and then the possibility of creating an opportunity to produce biodiesel fuel is given using an analytical method. Healion et al. [28] studied bioenergy training to develop a bioenergy project and investigate the training needs of the bioenergy sector in the Republic of Ireland.

2.2. Research Gap. In the conducted research studies, the topic of biomass and biomass energy development education in the agricultural sector was discussed and the major environmental issues caused by the increasing production of greenhouse gases were pointed out. The goal of the majority of research studies is the development and exploitation of alternative energies such as biomass. In research, the importance of developing education and learning about biomass energy has been discussed, especially in schools and large policy departments. In Table 1, the literature review is categorized.

3. Method

A descriptive-survey study was conducted on data collected through the library-field method using a mixed approach and grounded theory. There is a qualitative research method by which a theory is developed using a set of data based on three main stages of open coding, central coding, and selective coding. In this method, the research never starts from a theory to be proven, but it starts from a study period to show relevant cases. The developed grounded theory model was used to analyze the data, including the stage of open coding, central coding, and selective coding. The researcher conducts, reviews, and reads the data of the interviews concerning the education policy of biomass energy development in the agricultural sector. Similar data with the same semantic load are coded under common codes, and related concepts and categories are assigned to each. The researcher selected a main category (biomass energy education) extracted under the central coding of the data, which can

Table 1: Literature review.

Authors	Year	Goal	Fuel
Rhofita et al.	2022	Assess the energy production	Biomass
Lee et al.	2021	Discuss the technical and economic analysis of biomass	Biomass
Avcioglu	2019	Evaluate the energy potential of agricultural biomass	Agri-biomass
Aberilla et al.	2019	Providing energy from residual biomass	Biomass
Moratoa et al.	2019	Study on potential energy from agricultural biomass	Agri-biomass
This study	2022	Designing and explaining the policy model of biomass energy development education in the agricultural sector	Agri-biomass

find the origin and root of all topics related to the policy of biomass energy development education in the agricultural sector. In the next step, the relationship between the other categories and the main category is examined. Then, the theory related to the policy-making of biomass energy development education in the agricultural sector is created by reviewing, refining, and completing the categories and concepts extracted from the data. In the selective coding stage, biomass energy development education policy in the agricultural sector is described using new categories and concepts to describe the policy of education and development of biomass energy in the agricultural sector.

3.1. Data Analysis Method in the Qualitative Section. The main process in the grounded theory is the process of coding and classifying raw data and extracting the main concepts and categories and their relationships [33]. Therefore, the three stages of coding to analyze the data are as follows:

3.2. Open Coding. The first stage of open coding analysis is to conceptualize and categorize pieces of data under labels that simultaneously describe each piece of data [34]. Codes indicate how the data were selected, separated, and categorized to begin the analysis phase. The themes are at a low level of abstraction and originate from the researcher's initial question, concepts in the theoretical foundations, words that people have uttered in the social context of the event, or the new thoughts resulting from the researcher's immersion in the data [35, 36].

The second stage of data coding is conventional axial coding, which is the "second review" of the data. In the second review, the researcher focuses more on the primary coded themes than the data [35].

Axial coding is defined as creating a dense network of relationships around the "axes" of a category, in which each category can have two characteristics of property and dimension, and their combination leads to a pattern [37]. According to the role of the concepts obtained in the axial coding stage, the total categories extracted from the raw data are expressed in five modes and are linked through the paradigm model [33]. According to Strauss and Corbin, when this model is not used, the basic theory will lack the necessary precision and complexity (Figure 1):

Causal conditions: these conditions create a nucleic phenomenon

Contextual conditions: special conditions in which processes and interactions take place to manage, control, and respond to the phenomenon

Core category or phenomenon conditions: a mental form of phenomena as the basis of the process

Intervening condition: general conditions affecting processes and strategies which work to intensify or weaken the phenomena

Strategies (actions and interactions): behaviors and interactions that take place under the influence of intervening and contextual conditions

Consequences: the result of interactions [34]

3.3. Selective Coding. Selective coding reviews all previous data and codes in detail. At this stage, the researcher selectively looks for items representing the themes to compare them after data collection [35].

At this stage, the researcher analyzes the data in depth and presents them in the form of a theory that is the grounded data theory for understanding the situation. The research process draws other categories around the core category in the form of a paradigm model after determining the core or core category. The grounded or data-based theory should have three dimensions, including conditions, interactions, and consequences [35].

This study was conducted by the grounded theory based on a qualitative study. The data were collected in the framework of the qualitative method with the approach of the grounded theory using three stages of coding and required data with the benefit of semistructured interviews. Data analysis was performed based on Strauss's instructions, including the three main stages of coding: open coding, axial coding, and selective coding, and the hypothetical research model was obtained from the previously mentioned stages. The data were collected from interviews with managers and researchers familiar with education and biomass energy to create concepts for presenting policy-making models for the education and development of biomass energy in the agricultural sector. The interviews continued until reaching theoretical saturation by reviewing sources with ten experts, mainly managers in biomass energy development education and university researchers. Conducting this number of interviews and reviewing the sources showed that the collected information reached saturation, and there is no need to conduct more interviews. Finally, the collected data were

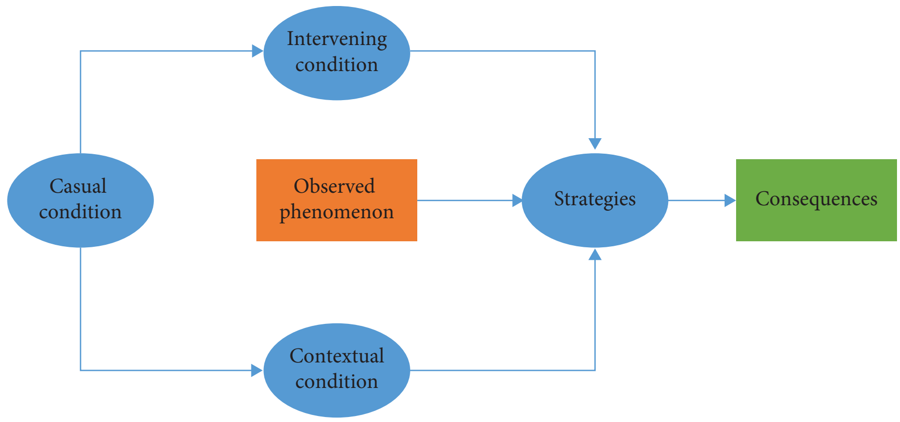

Figure 1: The visual model of the grounded theory [34].

analyzed using grounded analysis. The resulting data and concepts of the study were uploaded to the coding Tables 2–4 to select the main concepts and core categories.

The interviews were implemented, and the articles were reviewed by the method of qualitative content analysis and the two stages of open and case-centered coding to answer the first and second questions of the research study in the components and subcomponents and to determine the current state of education and training for the development of Zepast Tudeh energy in the agricultural sector. The coding process at the textual level was used to organize and manage the data for ease of work. In the open coding stage, the text of the interviews was examined line by line, and conceptualization and initial codes were extracted. Then, the primary codes extracted were compared several times to integrate some codes and create new codes (26 primary codes). In the central coding stage, the initial codes are categorized into seven groups of technical and managerial, structural and institutional, policy and planning, educational and knowledge, attitudinal, financial and credit, service and support components based on similarity, conceptual connection, and common features. According to the approach governing the data analysis process, the results of the literature review and the theoretical foundations of the research were used during the axial coding process to identify the main concepts and classify the primary codes in the form of secondary codes.

3.4. Solution Procedure. In this research, to analyse the data, we used the structural equation model (SEM) using AMOS software. The proposed framework for establishing the considered case study, which is based on structural equations, is generally possible in four stages which are as follows:

(1) Identify effective components and subcomponents of biomass energy development education in the agricultural sector
(2) Determine the impact of each component and subcomponents of biomass energy development education in the agricultural sector
(3) Calculate the degree of relationship between observed and latent factors
(4) Introduce a structural equation model and convert the current situation to the proposed desired situation

Stage 1. Identify effective components and subcomponents of biomass energy development education in the agricultural sector

In this step, we first divide the influencing factors into two groups of observed and hidden variables. Observed variables are those variables that are determined using an internal systematic study such as criteria that can affect the organization's process. Studying the observed variables in organizations is important because it can always be useful for the analyst in identifying the hidden variables of the organization in question. But in order to study and perform statistical analysis, we must divide these variables into groups so that we put the observed variables that are related to each other in one category, which are actually the same hidden variables. In this case, the latent variables cover the observed variables. It should be noted that in conceptual model design, hidden variables are always like model nodes. To achieve these variables, the use of data collection tools is a key factor. Questionnaires in this field can be of great help to an analyst. Before preparing the questionnaire, the necessary information should be collected using the library method. To complete this section, by reading books, articles, and research in the relevant field, the most important obvious variables can be found in this field.

Stage 2. Determine the impact of each component and subcomponents of biomass energy development education in the agricultural sector

This stage is implemented with the aim of providing a conceptual model of the organizational process that can show the relationships between factors well. In other words, at this stage, we seek to determine the logical relationships between the hidden variables and other variables. Latent variables are divided into dependent variables and independent variables. Coefficients are actually what we are looking to calculate, based on which the relationship of variables is measured. The coefficient of an independent latent variable is equal to λ, the coefficient of an independent

Table 2: Initial codes resulting from qualitative data content analysis (policy training for biomass energy development in agriculture).

No.	Initial codes	Frequency
1	Lack and incompatibility of biomass energy with farm conditions	28
2	The traditional attitude of farmers towards plowing and removing plant residues from the soil surface	26
3	Lack of a strategic and long-term plan to develop biomass energy in the country	25
4	Improper management of plant residues at the field level (burning, livestock grazing, etc.)	25
5	Lack of specific and binding laws to support biomass energy	23
6	Farmers' limited access to inputs (herbicides, seeds, fertilizers, etc.)	23
7	Allocation of funds and small credits for developing biomass energy	21
8	Little ability of farmers to train biomass energy due to the complex nature of biomass energy	21
9	Little knowledge and experience of farmers regarding biomass energy education	20
10	Temporary reduction of the economic efficiency of the product in the early years of biomass energy implementation	19
11	The possible risk of crop reduction in the early years and farmers' ability for acceptance	19
12	Having few bank facilities and financial resources to buy tools	19
13	Misunderstanding of planners, researchers, experts, and farmers about biomass energy	17
14	Lack of biomass energy knowledge among researchers, policymakers, managers, and experts	1
15	Weak performance of the promotion system in disseminating biomass energy knowledge and information to users	16
16	Failure to use cooperative and user-oriented models in biomass energy research	15
17	Inconsistency between biomass energy policies and other agricultural sector policies	14
18	Lack of applied research in various fields of biomass energy in Iran	14
19	Inconsistency between relevant organizations and institutions in the process of policy-making and implementation of biomass energy	13
20	Lack of network communication between actors of biomass energy development	13
21	Lack of proper insurance coverage for biomass energy	12
22	Absence of subsidy policies to support biomass energy	11
23	Lack of regulatory procedures to control the effective implementation of policies and programs	10
24	Lack of attention to the teaching of biomass energy concepts in agricultural colleges and conservatories	10
25	Failure to use the capacity of nongovernmental organizations in biomass energy development programs	9
26	Poor structure and low percentage of organic matter in agricultural soils of Iran	8

Table 3: Secondary codes resulting from qualitative data content analysis (biomass energy development education policy in agriculture).

Symbol	Initial codes	Secondary codes
TMB1	Improper management of plant residues at the farm level	Technical and managerial
TMB2	Poor structure and low percentage of organic matter in agricultural soils of Iran	
TMB3	Little skill of farmers in biomass energy training due to the complex nature of biomass energy	
TMB4	Increasing weeds and little experience of farmers in biomass energy management	
SIB1	Failure to use the capacity of nongovernmental organizations in biomass energy development programs	Structural and institutional
SIB2	Absence of specific and binding laws to support biomass energy	
SIB3	Inconsistency between relevant organizations and institutions in the process of policy-making and program implementation	
SIB4	Absence of network communication between actors of biomass energy development	
PPB1	Absence of a strategic and long-term plan for developing biomass energy in the country	Policy-making and planning
PPB2	Lack of regulatory procedures to control the effective implementation of policies and programs	
PPB3	Inconsistency between biomass energy policies and other sector policies	
PPB4	Lack of using participatory and user-oriented models in planning	
EKB1	Lack of applied research in different fields of biomass energy	Educational and scientific
EKB2	Lack of attention to biomass energy education in agricultural colleges and conservatories	
EKB3	Poor performance of the promotion system in disseminating biomass energy knowledge to users	
EKB4	Lack of biomass energy knowledge among researchers, policymakers, managers, and experts	
AB1	The traditional attitude of farmers towards plowing and removing plant residues from the soil surface	Attitudinal
AB2	Misunderstanding of biomass energy by planners, researchers, and experts	
FCB1	Allocation of funds and small credits for the development of biomass energy	Finance and credit
FCB2	Temporary reduction in the economic efficiency of the product in the early years of biomass energy implementation	
FCB3	The small financial ability of farmers to accept the risk of crop reduction in the early years	
FCB4	Having few bank facilities and financial resources to buy tools	
SSB1	Absence of subsidy policies to support biomass energy	Service and support
SSB2	Lack of proper insurance coverage for biomass energy	
SSB3	Limited access of farmers to institutions	
SSB4	Lack and incompatibility of biomass energy machines and tools with farm conditions	

Table 4: Selective coding results.

Category type	Category	Concepts
Casual conditions	The necessity of agricultural development	Lack of understanding of the necessity of developing biomass energy education in the agricultural sector
	Creating and strengthening the intellectual and belief structure in society	Lack of belief in biomass energy training in the agricultural sector among managers and experts Lack of cultural infrastructure for the development of biomass energy education in the agricultural sector Building trust between farmers and agricultural experts Attention to the values and religious beliefs of farmers Creating platforms for the acceptance of biomass energy education in the agricultural sector
	Compilation and implementation of the strategic plan for agricultural development	Lack of strategies to develop biomass energy education Adopting incentive policies for conservation tillage and preservation of remains Adopting policies to prevent plowing, burning, and harvesting of residues
	Increasing agricultural knowledge and awareness	Absence of pathological studies on implementing biomass energy education in the agricultural sector Little knowledge of farmers about biomass energy training in the agricultural sector The importance of changing the attitude and vision of managers, experts, and farmers
Core category or phenomenon conditions	Physical organizations	International Organizations, Ministry of Agricultural Jihad, Ministry of Energy, Agricultural Research Centers in Provinces, Universities and Agricultural Training Centers, Environmental Organization, Ministry of Industry, Mine and Trade, and Energy Organization
	Terms and Conditions	Soil Protection Law Rules for the production and import of agricultural tools and machinery Regulations related to energy and the environment
	Norms and values	The importance of protecting water and soil resources Reviving the sense of moral obligation to protect the basic resources of production Common norms and values of farmers and environmentally friendly traditions
Strategies (actions and interactions)	Creating and strengthening the biomass energy education innovation network	The importance of biomass energy training databases in the agricultural sector Strengthening communication links between the beneficiaries of biomass energy education in the agricultural sector
	Creating and strengthening research, promotion, and education centers	Continuous training of agricultural experts on biomass energy education in the Department of Agriculture in related schools and colleges Establishing centers for applied research, training, and promotion of biomass energy education in the agricultural sector Cooperation of research, extension, and education departments
	Establishing model farms	Establishing biomass energy training research farms in the Department of Agriculture in each region Creating model and demonstrating farms for teaching biomass energy
	Establishment of specialized training offices for biomass energy development	Creation of specialized biomass energy training teams in the agricultural sector The importance of creating specialized biomass energy training offices in the agricultural sector in the provinces

Table 4: Continued.

Category type	Category	Concepts
Contextual conditions	Physical infrastructure	Drought and water crisis Manufacturers of educational tools and machines related to biomass energy in the agricultural sector Limited access of farmers to tools and machines for biomass energy training in the agricultural sector Improper operation of tools and machines in the agricultural sector Lack of independent training units related to biomass energy in the agricultural sector in the agricultural jihad
	Financial infrastructure	Increasing production costs Regulation of agricultural products market
	Knowledge infrastructure	Little awareness of agricultural researchers, researchers, and students on biomass energy education Little knowledge of agricultural sector managers and experts on education related to biomass energy
Intervening Condition	Strengthening communication between institutions and organizations	International organizations Parliament's Agriculture, Water, and Natural Resources Commission Ministry of Agricultural Jihad, Ministry of Energy, Agricultural Research Centers in the provinces, Universities and Agricultural Training Centers, Environmental Organization, Agricultural Service Centers, and Energy Organization Councils and village heads and nongovernmental organizations supporting the environment Strengthening communication links between the beneficiaries of biomass energy education in the agricultural sector
	Taking advantage of informal communication	Councils and village heads and nongovernmental organizations supporting the environment Taking advantage of informal relationships between farmers
	Using the media to increase awareness	Continuous and expertized information through the media
	Monitoring the implementation of biomass energy education	Monitoring the implementation of biomass energy training programs and plans in the agricultural sector Continuous monitoring of biomass energy training farms in the agricultural sector
Consequences	Creating and strengthening an empowering and supportive environment	Localization of tools and machines according to the conditions of each region Providing after-sales services for biomass energy training tools in the agricultural sector Provision of appropriate institutions Allocating subsidies to biomass energy training activities in the agricultural sector Granting loans and low-interest facilities to farmers Giving grants to tarsus farmers Creating and strengthening an empowering institutional environment
	Development of biomass energy education culture	Using the knowledge and experience of biomass energy training experts in the agricultural sector Creating a culture of biomass energy education in the agricultural society Creating the intellectual structure of biomass energy education in the agricultural sector
	Adoption and dissemination of biomass energy education	The importance of showing the results of biomass energy training in the agricultural sector to farmers Dissemination of biomass energy training in the agricultural sector by receiver farmers Creating platforms for the acceptance of biomass energy education in the agricultural sector
	Sustainable agricultural production using biomass energy development training	Sustainable management of water and soil resources Increased performance in the long term

latent variable is equal to the latent dependent variable which is equal to γ, and the coefficient of a latent variable is equal to β. If the coefficient is less than 0.3, the relationship is considered weak and we ignore that relationship. A factor loading between 0.3 and 0.6 is acceptable, and a factor loading greater than 0.6 is considered very favorable [36, 37]. The purpose is to determine the coefficients between the variables identified in the organization. For this purpose, a preliminary conceptual model should be designed at this stage.

Stage 3. Calculate the degree of relationship between observed and latent factors

At this stage, after designing the initial model in AMOS software and running the implementation from the initial model, the coefficients are determined by software if the variables and the model have adequate overlap. At this stage, it is necessary to report the output of software in different modes such as ESTIMATED and STANDARD to check the estimated coefficients.

Phase 1. Introduce a structural equation model and convert the current situation to the proposed desired situation

In this step, according to the output of AMOS software, the value of the P statistic for the model is calculated. Considering that the statistical analysis is performed in the 95% confidence interval, if the P value is calculated to be less than 0.05, then the model is statistically significant. In general, the lower the value of P, the better it is. Therefore, it can be concluded that the estimated model has good accuracy. In the ESTIMATED mode, if the variables have the interval range specified in the second phase, we select and leave the other variables. Finally, the path that leads us to the goal is chosen as the dominant strategy over other strategies.

4. Results

Figure 2 shows the general policy measurement model of biomass energy development education in agriculture using the grounded theory method. Also, Table 5 shows the statistical results of the biomass energy development education model in agriculture.

According to Table 6, the factor load of all the categories of the overall structure is appropriate and more than 0.5. In addition, the P value of all the items is less than 0.05, and all the categories related to the general variables significantly affect their measurement. The goodness–of-fit (GoF) indicators of the model have been modified, and the correlation between some categories has been considered for more improvement. Chi-square and REAMREA indicators were as much as 2.660 and 0.066, which are less than 5 and 0.1, respectively. In addition, FI, GFI, and TLI were 0.963, 0.902, and 0.951 (more than 0.9), respectively. AGFI was estimated to be 0.857, which is more than 0.8, but it is within its acceptable limit. Therefore, the model fits well with the data, and all the indicators are in the accepted range. The overall policy measurement model of biomass energy development education is accepted in final agriculture.

4.1. Fitting the Structural Model of the Policy-Making Pattern Related to Biomass Energy Development Training in Agriculture. Figure 3 demonstrates the results of fitting the structural equation model of the policy-making pattern related to biomass energy development training in agriculture.

The policy-making pattern related to biomass energy development training in agriculture is formulated using the significance test of the coefficient of the estimated paths when the quality of the structural equation model is appropriate. According to Table 7, chi-square indicators with a degree of freedom of 2.276 indicate the appropriate fit of the model, and the RMSEA 0.071, CFI 0.941, and TLI 0.929 indicators report the proper fit of the model. Moreover, the GFI (0.906) and AGFI (0.894) indicators are within their acceptable limit and show that the structural equation model fit of the policy-making pattern related to biomass energy development training in agriculture is accepted.

4.2. Relationships between Variables. T values and P values estimated in Table 8 determine the significance of the relationships between the structures. When the T statistic in the significance test of the relationship between two variables is estimated to be greater than 1.96 or smaller than −1.96 or when the P values of the paths are less than 0.05, then the relationship between the structures is accurate with 95% confidence.

The test statistic related to the path of causal conditions to phenomenon conditions of the policy-making pattern model related to the education of biomass energy development in agriculture is 12.523, which is greater than 1.96, and its P value is less than 0.05. In addition, the coefficient of this path was estimated to be 0.916, which is a positive value. Causal conditions directly and significantly affect the phenomenon conditions of the policy-making pattern model related to the education of biomass energy development in agriculture.

The test statistic related to the path of phenomenon conditions to policy-making pattern model strategies related to the education of biomass energy development in agriculture is 2.424, and the P value is estimated to be 0.015, which is less than 0.05. Moreover, the coefficient of this path is estimated to be 0.051, which is a positive value. Therefore, the phenomenon conditions have a direct and significant impact on the policy-making pattern model related to the education of biomass energy development in agriculture.

The test statistic related to the path of background conditions to the strategies was 1.992, P value was estimated to be 0.046 less than 0.001, and the coefficient of this path was estimated to be a positive value of 1.231. Thus, the background conditions have a direct and significant effect on the strategies of the policy-making pattern model related to the education of biomass energy development in agriculture.

Intervening conditions directly and significantly affect the strategies of the policy-making pattern model related to the education of biomass energy development in agriculture given that the test statistic related to the path of intervening conditions to strategies is 3.509, its P value is less than 0.001,

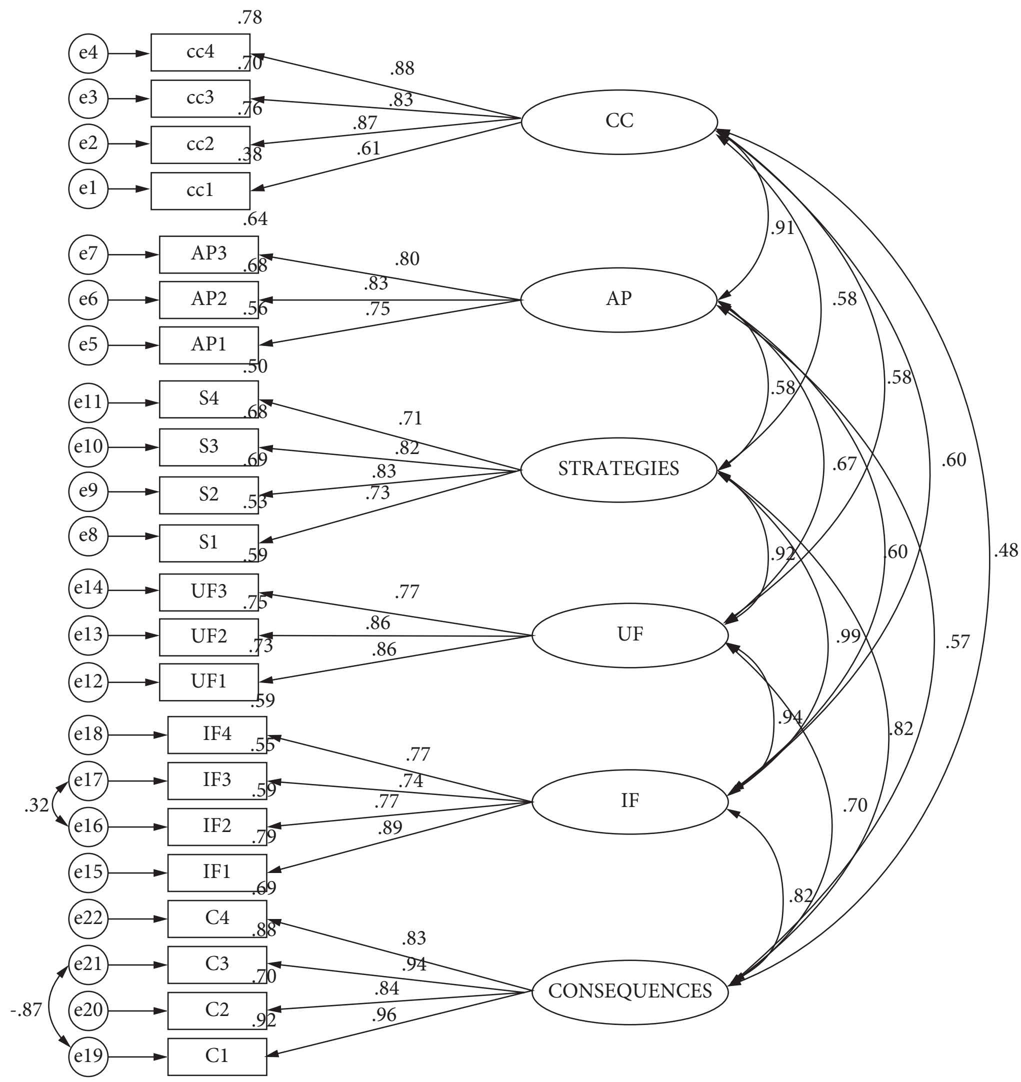

Figure 2: The total measurement model of the policy-making model of biomass energy development education in agriculture.

Table 5: Statistical results of the biomass energy development education model in agriculture.

Statistics	RMSEA	TLI	CFI	AGFI	GFI	Chi-square/df
Value	0.066	0.951	0.963	0.857	0.901	2.660

and the coefficient of this path is estimated to be 2.235, which is a positive value.

The strategies directly and significantly affect the consequences of the policy-making pattern model related to the education of biomass energy development in agriculture due to the path of strategies to consequences (14.406), with a P value of less than 0.001, and the path coefficient being 0.807. Table 9 presents the indirect relationships of the variables.

All relationships in Table 6 are significant, and the intervening, contextual, and phenomenon conditions of the policy-making pattern model related to the education of biomass energy development in agriculture indirectly have a positive and significant relationship with the results. The causal conditions indirectly have a positive and significant relationship with strategies and consequences. Therefore, the final policy-making pattern model related to the education of biomass energy development in agriculture does not need to be modified.

5. Managerial Insights

Important managerial insights and implications of the study are as follows:

Table 6: The total measurement model of the policy-making model of biomass energy development education in agriculture.

Category type	Symbol	Category	Symbol	Factor load	P value
Casual conditions	CC	The necessity of agricultural development	CC1	0.613	<0.001
		Creating and strengthening the intellectual and belief structure in society	CC2	0.872	<0.001
		Preparing and implementing a strategic plan for agricultural development	CC3	0.834	<0.001
		Increasing agricultural knowledge and awareness	CC4	0.881	<0.001
Core category or phenomenon conditions	AP	Physical organizations	AP1	0.748	<0.001
		Terms and Conditions	AP2	0.826	<0.001
		Norms and features	AP3	0.8	<0.001
Strategies	STRATEGIES	Creating and strengthening the biomass energy education innovation network	S1	0.729	<0.001
		Creating and strengthening centers for research, promotion, and education	S2	0.83	<0.001
		Establishment of model farms	S3	0.824	<0.001
		Establishment of specialized training offices for the development of biomass energy	S4	0.709	<0.001
Contextual conditions	UF	Physical infrastructure	UF1	0.857	<0.001
		Financial infrastructure	UF2	0.865	<0.001
		Knowledge infrastructure	UF3	0.771	<0.001
Intervening conditions	IF	Strengthening interinstitutional communication and organizations	IF1	0.887	<0.001
		Taking advantage of informal communication	IF2	0.767	<0.001
		Using the media to increase awareness	IF3	0.745	<0.001
		Monitoring the implementation of biomass energy education	IF4	0.77	<0.001
Consequences	CONSEQUENCES	Creating and strengthening an empowering and supportive environment	C1	0.958	<0.001
		Development of biomass energy education culture	C2	0.838	<0.001
		Adoption and dissemination of biomass energy education	C3	0.936	<0.001
		Sustainable agricultural production using biomass energy development training	C4	0.829	<0.001

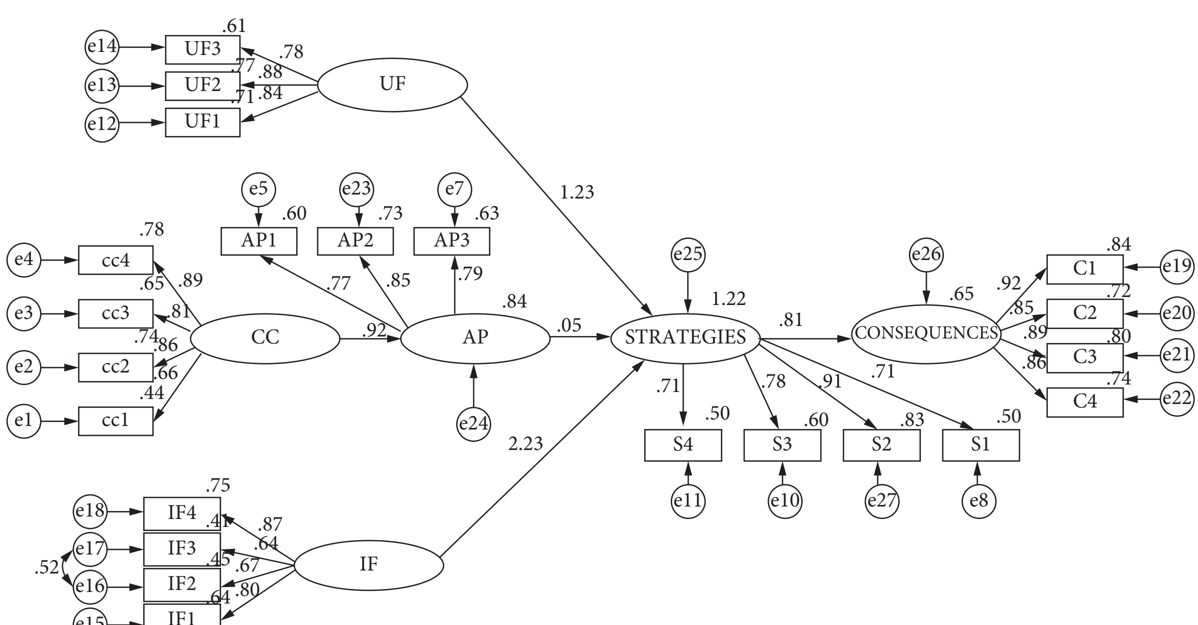

Figure 3: Structural model of the policy-making pattern related to biomass energy development training in agriculture.

Table 7: Statistically fitted model of biomass energy development training in agriculture.

Statistics	RMSEA	TLI	CFI	AGFI	GFI	Chi-square/df
Value	0.071	0.929	0.941	0.894	0.906	2.276

Table 8: Fitting the policy-making pattern model related to biomass energy development training in agriculture to investigate the direct relationships of variables.

Path			Coefficient	Standard error	T statistics	P value	Results
Casual conditions	<---	Core category or phenomenon conditions	0.916	0.091	12.523	<0.001	Significant
Core category or phenomenon conditions	<---	Strategies	0.051	0.015	2.424	0.015	Significant
Contextual conditions	<---	Strategies	1.231	0.535	1.992	0.046	Significant
Intervening conditions	<---	Strategies	2.235	0.58	3.509	<0.001	Significant
Strategies	<---	Consequences	0.807	0.072	14.406	<0.001	Significant

Table 9: The results of fitting the model to check the indirect relationships of the variables.

Variables	Total			Indirect		
	Phenomenon conditions	Strategies	Consequences	Phenomenon conditions	Strategies	Consequences
Intervening conditions	0	2.235	1.802	0	0	1.802
Contextual conditions	0	1.231	0.993	0	0	0.993
Causal conditions	0.916	0.047	0.038	0	0.047	0.038
Phenomenon conditions	0	0.051	0.041	0	0	0.041
Strategies	0	0	0.807	0	0	0

(i) Development has always been associated with increased energy use and rising greenhouse gases. Development without energy is impossible, and renewable energy is the best option to establish a balance. In addition, energy is the key and missing link to sustainable environmental development. Renewable energies imply access to new energy services for people, which is vital for fulfilling the eight millennium development goals. Sustainable development is traditionally analyzed in the three-dimensional economic, social, and environmental model. The relationship between sustainable development and renewable energy can be examined as a set of goals and limitations combined with global, regional, and local considerations. The positive role of renewable energy in promoting sustainable development should be considered at the international level and individually in a detailed evaluation.

(ii) However, the general role of this energy type and its relationship with the concept of sustainable development was investigated. Some of the critical goals are significantly affected by renewable energies, economic and social development, reduction of adverse environmental and health effects, climate change, and access to energy security. Reducing the amount of climate change because of human activities is the main and powerful motivation for using renewable energy technologies worldwide. Reducing the amount of climate change because of human activities is the main and powerful motivation for using renewable energy technologies worldwide. Awareness of capacities and reduction patterns is crucial in this regard, and technological capacities, costs, economic benefits, and energy policies differ from one society to another. The environmental and social effects of such technologies and their economic implications should be considered to ensure that the use of renewable energy is under the goals of sustainable development. In practice, governments have different goals of sustainable development according to their different priorities and levels of development, and the international community cannot be evaluated in a unified manner. For example, creating employment and improving the economic situation are the goals that lead governments to invest more in the use of renewable energy. The costs of electricity production and distribution from renewable energies are considered a determining factor in the desirability and acceptability of these energies. Therefore, an international regime of responsibility sharing can be investigated. Using renewable energy by diversifying energy sources and reducing dependence on specific suppliers guarantees energy security and can support the economy against price volatility.

(iii) In addition, renewable energies, especially for reducing greenhouse gas emissions, should play a role in achieving sustainable development goals. Renewable technologies play a major role in facilitating the fight against air pollution. Electricity production technologies based on renewable energy can significantly reduce the production of local and regional pollution with a significant advantage in improving human health compared to fossil fuels. Other positive effects of renewable energy-based technologies on nature are the effect on water resources and biodiversity. For example, water-cooled thermal power plants can damage this precious resource, while renewable technologies can provide needed services without stressing water resources. In addition, the deadly effect of renewable technologies on animal and plant species is much lower than traditional electricity production methods, with a positive role in protecting biodiversity. The benefits and positive role of using technologies based on renewable energy in helping to advance environmental goals seem more feasible than the role of these technologies in advancing economic and social goals. In relation to the following, the indicators of sustainable development and the relationship with renewable energies will be examined more closely.

(iv) Energy consumption is one of the inevitable necessities of human life. There is no possibility of activity without energy, and even a moment of life on this Earth is impossible. Despite the rapid development of technology, the increase in energy consumption is provided solely by fossil fuels. This style of energy supply raises new issues such as the limitation of oil reserves, the increase in oil extraction cost, and sensitive and limited relationships between certain regions and countries. More diversity in energy supply is one of the solutions to answer these issues, especially when this diversity is in renewable energy. Biofuels are more expensive than fossil fuels, but on the other hand, they have advantages such as not being threatened at an exponential rate and having few harmful effects on the environment.

6. Conclusion and Discussion

More than a decade has passed since the design and implementation of biomass energy system development programs by the Ministry of Agriculture Jihad and Environment, but its development and acceptance in the country are not in suitable and stable condition. According to experts, some farmers implement this method in their fields for one or two years after accepting this technology and then refer to common traditional methods. Considering the state of soil erosion and the reduction of organic matter, the increase in energy costs and other costs of biomass energy development is an inevitable necessity. The findings of the central and selective coding of the integrated institutional model for the development of biomass energy were presented to solve the shortcomings in the literature on the development and adoption of biomass energy. The essential and the most important components of the institutional model of physical organizations include international organizations, large policy-making organizations, research and educational organizations, executive organizations, service-providing organizations, and intermediary organizations, as well as laws, regulations, norms, and values. The biomass energy innovation network at the local level is at the center of this model, where the adoption and development of biomass energy happen because of the dynamic activities of this sector. This institutional framework operates in physical, financial, and knowledge infrastructure. Thus, the main results of the paper are as follows:

(i) Core category or phenomenon conditions to casual conditions' path with coefficient 0.916 is significant

(ii) Strategies to the core category or phenomenon conditions' path with coefficient 0.051 is significant

(iii) Strategies to contextual conditions' path with coefficients 1.231 is significant

(iv) Strategies to intervening condition path with coefficients 2.235 is significant

(v) Consequences to strategies' path with coefficients 0.807 is significant

Also, the main limitations of this paper are as follows:

(i) One of the limitations in the current research is the fear and nonresponse of the respondents to answer the questions; this causes the process of asking questions to be longer.

(ii) The extent of the policy components and indicators of biomass energy development education in the agricultural sector and its final exploitation in the interviews.

(iii) Time-consuming field studies and conducting exploratory interviews in order to extract indicators.

(iv) It is avoided to mention other limitations and implementation problems due to their relative importance.

(v) Hard access to experts according to the criteria set (expertise and experience) to conduct interviews. Another limitation of this research is the lack of resources to compare the results.

Finally, further study in the future suggest that by making tangible the various benefits of these fuels, which affect the lives of farmers themselves, their attitude towards these fuels can be improved. Considering the effect of justice on the moral norm, it is suggested to increase the experts' understanding of the fairness of the production and development of biofuels in rural areas, pay attention to the important role of farmers in this field, and create biofuel infrastructures in rural areas. This method increased people's understanding of the morality of biofuel production.

Through holding specialized courses, workshops, conferences, and seminars in the field of biofuels and emphasizing its advantages and the necessity of replacing them with fossil fuels, the knowledge of experts about the nature and benefits of biofuels and as a result, the desire to increase them in the promotion and development of agriculture increases. By linking fossil fuels with environmental degradation and climate change, it is possible to improve the understanding of professionals towards this innovation and then the attitude and ethical norms.

Data Availability

Data are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Dual-Channel Supply Chain Coordination with Loss-Averse Consumers

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Most studies on supply chain coordination assume that consumers are rational. However, with the development of e-commerce, consumer-bounded rationality has become an important issue with respect to supply chain coordination. Based on the assumption that some consumers are loyal to the offline shop and others are reference-dependent, this article examines the mechanism of vertical restraints and their competitive effects. This research study found that compared with the assumption of rational consumers used in previous literature, vertical restraints help internalize the "channel price gap externality" when consumers are loss averse. When separately operating, the offline shop will set a higher price due to its consumers' higher loyalty and willingness to pay. However, given the positive externality of this price to the online retail sales, the offline price is still lower than the level under vertical integration. When the upstream manufacturer achieves supply chain coordination with vertical restraint contracts, the channel price gap externality is internalized, and the channel price gap expands to stimulate loss-averse consumers' purchasing decisions.

1. Introduction

On August 12, 2016, the Shanghai Municipal Development & Reform Commission decided to impose administrative penalties on Chongqing Haier Home Appliance Sales Co., Ltd. Shanghai Branch and others for using minimum resale prices. According to the penalty decision, these three manufacturers involved entered into distribution contracts with downstream retailers to limit their minimum retail prices at different sales terminals. Since 2013, the three manufacturers sent monthly online and offline price lists to distributors by direct delivery or by mail, requiring that "the center's activities shall not be lower than this price in any form without filing." Through this distribution contract, these three upstream manufacturers, in effect, vertically constrained the supply chain by limiting the minimum resale prices of goods. Unlike the resale price maintenance cases investigated by the anti-monopoly bureau in the past, this case involved price maintenance that appeared to differ between the online and offline sales channels. In fact, in some markets, such as home appliances, there are clear and significant price gaps between online and offline channels. The existence of such price gaps has greatly facilitated the sales of home appliances in the online market. According to the "2015 China Online Home Appliance Shopping Analysis Report," the size of China's online home appliance market reached 2,007 billion in 2015, a 49% year-on-year increase. In stark contrast, the retail sales of offline home appliances fell by 3.8% during the same period. By observing the sales pages of online channels, it is easy to observe that labels such as "counter price" and "original price" frequently appear below the actual price to encourage consumers to purchase online. However, previous studies on supply coordination with resale price maintenance and other vertical restraints have not considered the impact of online and offline price gaps on consumer behavior [1–3].

With the continuous development of big data analysis technology and e-commerce, firms are able to adjust their pricing and marketing strategies by observing consumers' purchasing behaviors. Reference dependence and loss aversion are two typical behaviors associated with consumers' bounded rationality, and both are important core aspects of prospect theory. Reference-dependent consumers have a reference point when making purchase decisions. Thus, when consumers purchase a product with a price below the reference point, there is an additional psychological utility gain. In contrast, there is an additional psychological utility loss when purchasing at a price above the reference point. Thaler [9] first suggested that consumers are reluctant to buy a product at a price higher than the reference price because of the expected utility loss associated with paying more than the reference price. Consistent with this, there is a wealth of evidence from behavioral economics and marketing that suggests consumers are reference-dependent and exhibit loss aversion in their utility [10, 11]. Accordingly, loss-averse consumers incur greater subjective utility losses from losses relative to the utility improvement from gains of the same magnitude.

According to the abovementioned concepts, incorporating consumer loss aversion into a supply chain coordination model helps to explain price gaps and comprehensively analyze the welfare effect of vertical integration in such markets. Hence, based on the prospect theory, this article presents a possible mechanism for manufacturers in the multichannel retail industry to implement vertical restraints, such as resale price maintenance, in the presence of loss-averse consumers. Therefore, the main contributions of this article are as follows:

(1) This article presents a mathematical framework for analyzing dual-channel coordination when consumers are loss averse

(2) The model proposed in this article yields new economic insights in the competitive effect and anticompetitive effects of vertical restraints by relaxing the standard assumption that consumers are rational

(3) This analysis suggests that when consumers are bounded rationally, manufacturers have more incentive to impose vertical restraints

The remainder of the article is organized as follows. Section 2 presents a literature review, while Section 3 discusses the basic model. The results and sensitivity analyses are provided in Section 4, which is followed by a discussion of the managerial and antitrust policy insight in Section 5. Finally, Section 6 presents the conclusion, limitations of the study, and suggestions for further research studies.

2. Literature Review

Whether vertical restraints restrict channel competition is a current focus of industrial organization literature. However, the theory of vertical restraints is less well-developed than the mature theory of horizontal agreements. Many theoretical issues remain to be resolved. Nonetheless, most previous literature on vertical restraints and vertical integration assume that consumers are completely rational. Under this assumption, theoretical research can be divided into two branches. One branch argues that vertical coordination adheres to the efficiency promotion theory, while the other branch argues that the anticompetitive effect dominates. Efficiency promotion theory suggests that vertical restraints improve coordination among the components of the vertical value chain and increase consumer surplus and total social welfare by eliminating double markups [1, 2], thereby solving the problem of service free-riding among retailers [3] and signaling quality information about goods signaling quality information about goods [4, 5]. The anticompetitive effects of vertical restraints are reflected in weakening inter-brand competition [6], facilitating collusion among manufacturers [7], and promoting the leverage effect and the exclusion effect [8].

However, a large body of evidence from behavioral economics suggests that consumers are not fully rational (or boundedly rational). Heidhues and Kőszegi [12] first introduced consumer loss aversion into the context of monopoly pricing and competitive pricing. Zhou [13] also found that loss aversion can reduce market competition by driving consumers to choose the price of a competitor's product in the market as the reference price when making a purchase decision in the model. The selection of reference prices in our article continues this hypothesis. Rosato [14], on the contrary, considered the strategies of manufacturers that sell multiproduct substitutes when consumers are loss averse. Scholars such as Schweitzer and Cachon [15], Liu et al. [16], and Nagarajan and Shechter [17] extended the newsvendor model based on the prospect theory to analyze the strategy formulation of loss-averse decision makers. Wang [18] further developed a newsvendor model to study a competitive market with multiple loss-averse retailers. Liu et al. [19] and Qiu et al. [20] studied a loss-averse newsvendor problem with reference dependence, while Zhou et al. [21] compared the impact of static loss-averse behaviors and dynamic loss-averse behaviors of retailers with demand uncertainty on the decisions and utilities of the supply chain. In this article, we consider both reference dependency and loss aversion of consumers.

The article is also related to the stream of research on supply chain coordination. Wang and Webster [22] examined the mitigating effect of gain/loss-sharing-and-buy-back contracts on the loss-aversion effect and the manufacturer's formulation of its contract with the retailer to coordinate the supply chain in a decentralized supply chain model consisting of a risk-neutral manufacturer and a loss-averse retailer. Chen et al. [23] compared the difference in decision-making between a loss-averse and a risk-neutral retailer in a supply chain model with short life-cycle products and analyzed the supply chain coordination problem in the presence of a loss-averse retailer. Hu et al. [24] found that the formulation of revenue-sharing contracts in a three-echelon supply chain model with a loss-averse retailer can achieve a Pareto improvement. Du et al. [25], who considered both suppliers with yield randomness and retailer with demand uncertainty loss aversion, derived the optimal strategy and illustrated the effect of loss aversion and yield randomness on supply chain performance. Liu et al.

[26] designed a contract that combined buyback and quantity flexibility to coordinate the supply chain with loss-averse retailers. Xie et al. [27] investigated a single-period two-echelon supply chain where the loss-averse retailer's marketing efforts influence the final market demand. In the scenario of random production and demand, Yueli et al. [28] researched the supply chain coordination with capital constraint and the loss-averse retailer. Some literature focused on the coordination of a dual-channel supply chain under the condition of loss aversion. Huang et al. [29] proposed a combined contract consisting of option and cost-sharing to achieve supply chain coordination and Pareto-improvement in a model with a loss-averse manufacturer and a risk-neutral retailer.

With the development of the Internet economy, a growing volume of literature extends supply chain issues to online channels. Shi et al. [30] examined the impact of different return strategies in a dual-channel supply chain model. Liu et al. [31] modeled a dual-channel supply chain with loss-averse consumers and classified products into basic products and luxury goods to determine the optimal price strategy. Tian et al. [32] focused on a dual-channel supply chain's pricing and channel differentiation strategy. Many scholars have considered additional factors in supply chain design. Lotfi et al. [33] reduced the costs of high-demand supply chains by establishing blockchain technology for transactions with cryptocurrency. Goli et al. [34] considered fuzzy uncertainty in the multi-objective, multi-product, and multi-period closed-loop supply chain network design and optimized the physical and financial flow in the supply chain. Alinezhad et al. [35] focused on the sustainability issues in a closed-loop supply chain network under uncertain conditions based on fuzzy theory. Lotfi et al. [36] applied hybrid fuzzy and data-driven robust optimization in designing resilience and sustainable healthcare supply chain with a vendor-managed inventory approach to tackle uncertainty and disruption.

2.1. Research Gap. According to the abovementioned studies, a large body of previous literature on the effect of vertical restraints assumes that consumers are perfectly rational. Unlike the traditional vertical restraint model, this article assumes that one fraction of consumers consists of loyal consumers of offline shops and that the other fraction is reference-dependent and then compares the competitive situation under the vertical decentralization structure and the vertical restraint structure. This article also investigates the theoretical mechanism of vertical restraints imposed by manufacturers, while, considering that partial consumers are loss averse to provide theoretical support for relevant antitrust cases. We indicate the similarities and differences between some of the relevant literature and this artical in Table 1.

Within the theoretical framework, some novel results are obtained. In the case of vertical restraints, manufacturers have an incentive to maintain a certain level of price gap to stimulate sales in the online channel. Although offline prices increase under vertical restraints, the latter eliminates the two-part markup, reduces average prices, and increases the total sales, which thereby improves social welfare. Hence, by relaxing the standard assumption that consumers are rational, the model proposed in this article yields new economic insights into the competitive effect and anticompetitive effects of vertical restraints. For antitrust policies, this article suggests that when consumers are bounded rationally, manufacturers have a greater incentive to impose vertical restraints. This factor should be taken into consideration when dealing with related cases.

Our model step is shown in Figures 1 and 2.

3. Problem Statement

We consider a two-tier supply chain consisting of a single manufacturer and two downstream retailers: retailer 1 and retailer 2. Retailer 1 is brick-and-mortar and retailer 2 is online. Then, the two retailers compete on price. The bricks-and-mortar retailer is the price leader in the downstream market [37, 38] and has a pool of loyal consumers due to its reputation and history, whereas the online shop does not have loyal consumers but is able to attract some consumers who are more sensitive to the price gap and are loss averse. Such consumers will make purchases from the lower-priced retailer.

Therefore, we suppose that there are two types of consumers. The total number of consumers is normalized as follows. We assume that A-type consumers are loyal consumers who buy only from retailer 1, accounting for a proportion of λ of the total. B-type consumers are loss-averse consumers, accounting for a proportion of $1-\lambda$ of the total. B-type consumers make choices by comparing the two retailers' prices (see Figure3).

To define the research question and to facilitate the construction of the subsequent model, the following assumptions are made:

(1) In the process of the game, all participants are information-symmetric and risk neutral.

(2) The utility function of a representative A-type consumer is $U_A = v(q_A) - p_1 q_A$, where q_A is the quantity purchased by A-type consumers, $v(q_A)$ is the gross utility of A-type consumers, and p_1 is the price of retailer 1's product.

(3) Based on the loss-averse consumer utility function in the literature [12, 13], we assume that the utility function of a representative B-type consumer buying from retailer i is $U_{Bi} = v(q_{Bi}) - q_{Bi}p_i + \beta q_{Bi}\max\{p_j - p_i, 0\} - \beta_1 q_{Bi} \times \max\{p_i - p_j, 0\}$ $(i = 1, 2;\ i \neq j)$, where $0 < \beta < 1$ denotes the utility gain coefficient when the price of the product actually purchased by the consumer is lower than its psychological price point, $\beta_1 > \beta$ denotes the utility loss coefficient when the actual price of the product purchased by the consumer is higher than its psychological price point, and q_{Bi} denotes the quantity purchased by B-type consumers from retailer i. For the simplicity of analysis, we assume that loss-averse consumers choose to make purchases from the lower-priced retailer after comparing prices, and this assumption is

Table 1: Literature comparison.

Author	Year	Dual channel	Coordination	Consumer loss aversion	Manufacturer loss aversion	Retailer loss aversion	Impact on social welfare
Du et al.	2018	—	√	—	√	√	—
Zhou et al.	2018	—	—	—	—	√	—
Liu et al.	2019	√	√	√	—	—	—
Huang et al.	2019	—	√	—	√	—	—
Liu et al.	2020	—	√	—	—	√	—
Liu et al.	2020	—	—	—	—	√	—
Xie et al.	2021	—	√	—	—	√	—
Qiu et al.	2021	—	—	—	—	√	—
Tian et al.	2022	√	√	—	—	—	—
Yueli et al.	2022	—	√	—	—	√	—
This research	2022	√	√	√	—	—	√

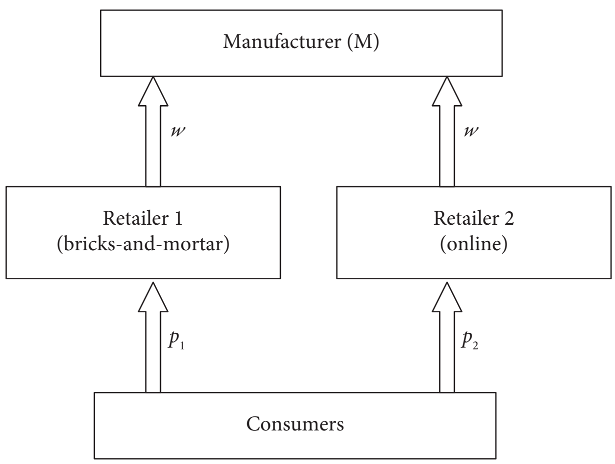

Figure 1: Decentralized model (p_1 and p_2 are set by retailers, respectively).

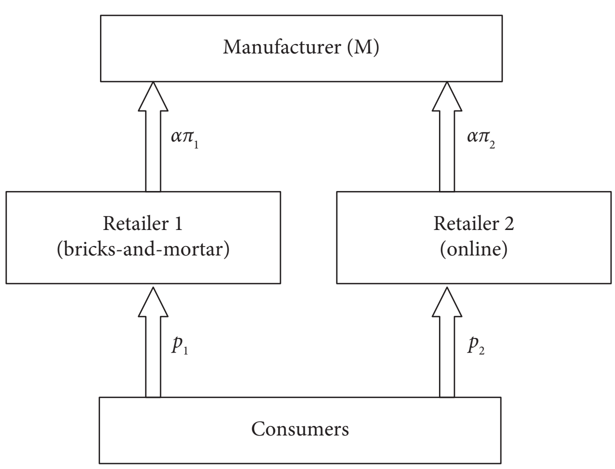

Figure 2: Centralized model (p_1 and p_2 are set by the manufacturers).

also consistent with what occurs in reality. Therefore, the last term of the utility function disappears.

(4) Assuming that $v(q) = [1 - (1 - q)^2]/2$, the demand function of A-type consumers of retailer 1 can be obtained by a simple calculation, that is, $q_A = 1 - p_1$; the demand function of B-type consumers of retailer i is

$$q_{Bi} = \begin{cases} 1 - p_i + \beta(p_j - p_i), & \text{if } p_i < p_j, \\ \dfrac{(1 - p_i)}{2}, & \text{if } p_i = p_j, \\ 0, & \text{if } p_i > p_j. \end{cases} \quad (1)$$

The demand of retailer 1 comes from both types of consumers, while that of retailer 2 comes solely from B-type consumers. The aggregate demand function for each of the two retailers can be obtained by summing the equations horizontally as $q_1 = \lambda q_A + (1 - \lambda)q_{B1}$ and $q_2 = (1 - \lambda)q_{B2}$.

The two following scenarios are considered:

(1) Separate operation (SP): the upstream manufacturer and downstream retailers make decisions individually.

(2) Vertically integrated operation (VI): the upstream manufacturer and downstream retailers coordinate and then make centralized decisions. The manufacturer can achieve maximum supply chain profits through vertical contracts, such as retail price maintenance and two-part tariffs.

The notations used in this article are described in Table 2.

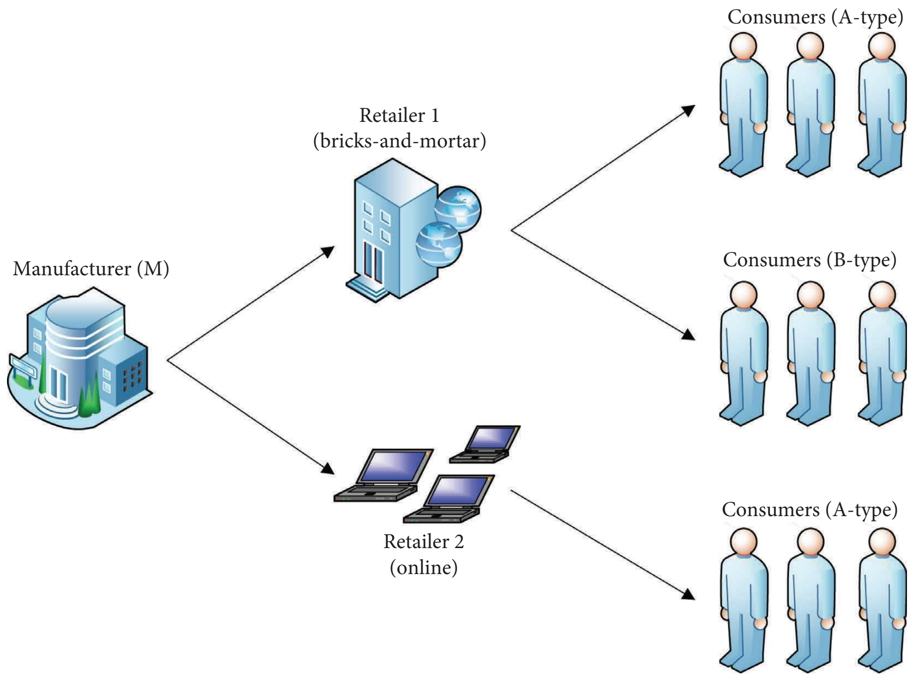

FIGURE 3: Diagram of the model structure.

TABLE 2: Summary of notations.

Notations	Definition
Indices	
A	Retailer 1's loyal consumers
B	Loss-averse consumers
i, j	Represent retailers
SP	Separate operation model
VI	Vertically integrated operation model
Parameters	
λ	The proportion of A-type consumers
$1-\lambda$	The proportion of B-type consumers
U	Utility that a representative consumer derives from the product
v	Total utility that consumers derive from the product
q_A	Quantity purchased by A-type consumers
q_B	Quantity purchased by B-type consumers
q_1	Demand for retailer 1
q_2	Demand for retailer 2
β	Utility gain coefficient
β_1	Utility loss coefficient
α	The proportion of profit that the manufacturer can get from the vertical coordination chain
π_1	The profit of retailer 1 in SP
π_2	The profit of retailer 2 in SP
π_{vi}	The profit of the integrated manufacturer
π'_{vi}	The profit of the integrated manufacturer under $p_2 > p_1$
π''_{vi}	The profit of the integrated manufacturer under $p_2 = p_1$
π'''_{vi}	The profit of the integrated manufacturer under $p_2 < p_1$
Q^{VI}	Total sales in VI
Q^{SP}	Total sales in SP
CS^{VI}	Consumer surplus in VI
CS^{SP}	Consumer surplus in SP
Decision variables	
w	The wholesale price of the upstream manufacturer
p_1	Price set by retailer 1
p_2	Price set by retailer 2

3.1. Decentralized Decision-Making. In a decentralized decision-making situation, an upstream manufacturer first sets the wholesale price, and then, downstream retailers compete on price. In contrast to a traditional vertical restraint study, this article assumes that consumers will use the prices of other channels as their reference prices when making purchase decisions. This channel price gap will affect consumers' utility and purchase decisions as some consumers are loss averse. In this case, this article identifies another form of price externality, that is, an increase in the price of the higher-priced channel expands the price gap between the two channels, thereby increasing the efficiency of the lower-priced channel. At the end of this section, we present a detailed analysis of this externality and its impact on competition.

In the first stage, the manufacturer with zero marginal cost sets a uniform wholesale price w $(0 < w < 1)$ of the product for both retailers; in the second stage, retailer 1 sets price p_1 after observing the wholesale price of the product; in the third stage, retailer 2 sets price p_2 after observing the wholesale price and retailer 1's price. We solve the subgame perfect Nash equilibrium (SPNE) of the model by backward induction.

In the third stage, given the upstream manufacturer's wholesale price w and retailer 1's price p_1, retailer 2's profit function is expressed as

$$\pi_2 = \begin{cases} (p_2 - w)(1-\lambda)(1 - p_2 + \beta(p_1 - p_2)), & \text{if } p_2 < p_1, \\ (p_2 - w)(1-\lambda)(1-p_2)/2, & \text{if } p_2 = p_1, \\ 0, & \text{if } p_2 > p_1. \end{cases} \tag{2}$$

Depending on the profit function of retailer 2, we must analyze it from several perspectives. First, we assume that, given p_1, retailer 2 considers the case of pricing $p_2 < p_1$ with a profit function that needs to be optimized as $\max_{p_2}\pi_2 = (p_2 - w)(1-\lambda)(1 - p_2 + \beta(p_1 - p_2))$. By solving the first-order condition, we obtain $p_2 = (1 + \beta p_1 + (1+\beta)w)/(2(1+\beta))$. Since $p_2 < p_1$ holds, so we can obtain $p_1 > (1 + (1+\beta)w)/(2+\beta)$; at this point, the profit of retailer 2 is $\pi_2 = ((1-\lambda)(1 - w + \beta(p_1 - w))^2)/(4(1+\beta))$.

When $p_1 \leq (1 + (1+\beta)w)/(2+\beta)$, there are two pricing strategies for retailer 2. If the price is set at $p_2 = p_1$, then the profit it will earn is $\pi_2(p_1, w) = (p_1 - w)(1-p_1)(1-\lambda)/2$, while if the price is set at $p_2 = p_1 - \varepsilon$ (where ε is an arbitrarily small constant), retailer 2 will be able to capture the market of loss-averse consumers and earn a profit of $\pi_2(p_1, w) \approx (1-\lambda)(p_1 - w)(1-p_1)$. Obviously, retailer 2 will set the price as $p_2 = p_1 - \varepsilon$.

Therefore, retailer 2's pricing strategy is

$$p_2 = \begin{cases} \dfrac{1 + \beta p_1 + (1+\beta)w}{2(1+\beta)}, \text{if } p_1 > \dfrac{1 + (1+\beta)w}{2+\beta}, \\ p_1 - \varepsilon, \text{if } p_1 \leq \dfrac{1 + (1+\beta)w}{2+\beta}. \end{cases} \tag{3}$$

The profit function of retailer 2 is

$$\pi_2 = \begin{cases} \dfrac{(1-\lambda)(1 - w + \beta(p_1 - w))^2}{4(1+\beta)}, & \text{if } p_1 > \dfrac{1 + (1+\beta)w}{2+\beta}, \\ (p_1 - w)(1-\lambda)(1-p_1), & \text{if } p_1 \leq \dfrac{1 + (1+\beta)w}{2+\beta}. \end{cases} \tag{4}$$

In the second stage, retailer 1 with rational expectations recognizes that in the absence of vertical restraints, regardless of its pricing $p_1 > (1 + (1+\beta)w)/(2+\beta)$ or $p_1 \leq (1 + (1+\beta)w)/(2+\beta)$, attracting B-type consumers is impossible; then, its profits can only come from the consumption of loyal consumers. Retailer 1's profit function is $\pi_1(w) = \lambda(1-p_1)(p_1 - w)$; it is easy to use the first-order conditions to find the optimal pricing of retailer 1 in the second stage, $p_1 = (1+w)/2$. Then, the sales of retailer 1 at this time are $q_1 = (1-w)\lambda/2$, and its profit is $\pi_1 = (1-w)^2\lambda/4$. Thus, we know that $p_1 > (1 + (1+\beta)w)/(2+\beta)$. Bringing p_1 into the equilibrium solution in the third stage, we can obtain $p_2 = (2 + \beta + (2+3\beta)w)/(4(1+\beta))$ and $q_2 = (1-\lambda)(2+\beta)(1-w)/4$; therefore, the profit of retailer 2 is $\pi_2 = (2+\beta)^2(1-\lambda)(1-w)^2/16$.

In the first stage, the upstream manufacturer chooses the wholesale price to maximize its profit, thus its profit function is $\max_w w(q_1 + q_2)$. Solving this maximization problem after introducing the results obtained above yields the detailed form. From this, we can obtain Proposition 1.

Proposition 1. *In the case of decentralized decision-making, the manufacturer's wholesale price is* $w = 1/2$ *in the equilibrium; the retailers' pricing and sales are* $p_1 = 3/4$, $p_2 = (6+5\beta)/(8+8\beta)$, $q_1 = \lambda/4$, *and* $q_2 = (2+\beta)(1-\lambda)/8$ *in the equilibrium.*

When the upstream and downstream firms make decisions separately, the offline shop and the online shop will set different prices, thus serving different types of consumers. The offline shops target and price for their loyal consumers to maximize profits.

The game and equilibrium analysis are under separate operation, and thus, they are the basis for analyzing the competitive effects of vertical restraints. When there are no vertical restraints, online shops effectively exploit the prices of offline shops to constitute the price gap, thus promoting loss-averse consumer spending. This channel price gap externality is internalized in the presence of vertical restraints so that manufacturers have an incentive to exploit this consumer psychology to stimulate sales, which is a direct incentive for upstream manufacturers to impose vertical restraints that has not been considered in the previous literature.

3.2. Centralized Decision-Making. Under centralized decision-making, all supply chain members attempt to maximize overall profits, which is equivalent to vertically integrating upstream manufacturers with downstream retailers and online shops. However, there are still two sales channels, namely, offline shops and online shops. In fact, manufacturers can achieve the effect of vertical integration with various vertical restraint tools. The profit function of the integrated firm is $\pi_{vi} = p_1 q_1 + p_2 q_2$. The firm needs to make decisions on both p_1 and p_2, and since the channel through which B-type consumers buy depends on which channel has a lower price, it needs to be analyzed in three cases according to the magnitude of p_1 and p_2.

(1) When $p_2 > p_1$, both types of consumers purchase in the offline shop, $q_1 = 1 - p_1 + (1-\lambda)\beta(p_2 - p_1)$ and $q_2 = 0$; therefore, the profit of the integrated manufacturer is $\pi_{vi} = p_1(1 - p_1 + (1-\lambda)\beta(p_2 - p_1))$. It is easy to obtain the price $p_1 = (1 + \beta(1-\lambda)p_2)/(2 + 2\beta(1-\lambda))$ in equilibrium using the first-order condition $\partial\pi_{vi}/\partial p_1$. In addition, we find that $\partial\pi_{vi}/\partial p_1 = p_1(1-\lambda)\beta > 0$. This shows that although there are no sales in channel 2 at this time, increasing the pricing in channel 2 can enhance the pricing in channel 1 and thus improve the total profit. In reality, the cost of maintaining a retail outlet is high, and manufacturers typically offer official websites to provide reference prices, publish suggested retail prices, or open direct sales on the Internet to make consumers use this price as a reference price, thus further promoting the demand for offline retailers.

According to the assumptions of the basic model, $p_2 \in [0,1]$, so $p_2 = 1$; thus, we can obtain the equilibrium solution when $p_2 > p_1$:

$$p_1 = \frac{1+\beta(1-\lambda)}{2+2\beta(1-\lambda)} = \frac{1}{2},$$
$$q_1 = 1 - p_1 + (1-\lambda)\beta(p_2 - p_1) = \frac{1+\beta(1-\lambda)}{2}, \tag{5}$$
$$\pi'_{vi} = (p_1 - c)q_1 = \frac{1+\beta(1-\lambda)}{4}.$$

(2) When $p_1 = p_2$, the offline shop will share B-type consumers equally with the online shop, so the demands of the integrated manufacturer are $q_1 = \lambda(1-p_1) + (1-\lambda)(1-p_1)/2$ and $q_2 = (1-\lambda)(1-p_2)/2$. The manufacturer's profit maximization problem is

$$\max_{p_1,p_2} p_1\left(\lambda(1-p_1) + \frac{(1-\lambda)(1-p_1)}{2}\right) + \frac{p_2(1-\lambda)(1-p_2)}{2} \tag{6}$$
$$\text{s.t. } p_1 = p_2.$$

By solving this maximization problem, we obtain $p_1 = p_2 = 1/2$. Thus, in this case, the manufacturer's profit is $\pi''_{vi} = 1/4$.

(3) When $p_2 < p_1$, B-type consumers all purchase in the online shop. The demands of the integrated manufacturer are $q_1 = \lambda(1-p_1)$ and $q_2 = (1-\lambda)((1-p_2) + \beta(p_1 - p_2))$. The profit function is $p_1\lambda(1-p_1) + p_2(1-\lambda)(1 - p_2 + \beta(p_1 - p_2))$, and the first-order conditions are $\lambda(1-2p_1) + \beta p_2(1-\lambda) = 0$ and $(1-\lambda)(1 - p_2 + \beta(p_1 - p_2) - (1+\beta)p_2) = 0$. By solving the conditions, we obtain $p_1 = (2\lambda + \beta(1+\lambda))/((2+\beta^2)\lambda - \beta^2)$ and $p_2 = ((2+\beta)\lambda)/((2+\beta^2)\lambda - \beta^2)$. The price gap between the two channels is $p_1 - p_2 = \beta/((2+\beta^2)\lambda - \beta^2) > 0$, satisfying the assumption. We can calculate the manufacturer's profit in this case as $\pi'''_{vi} = (1+\beta)\lambda/((2+\beta^2)\lambda - \beta^2)$.

By a simple calculation, we find that $\pi'_{vi} > \pi''_{vi}$. Comparing π'''_{vi} and π'_{vi} indicates that in the range of $\beta \in [0,1]$ and $\lambda \in [\beta^2/(2+\beta)^2, (\beta+\beta^2)/(2+\beta)^2]$, we have $\pi'''_{vi} > \pi'_{vi}$; in other ranges, we have $\pi'''_{vi} < \pi'_{vi}$. Therefore, when the relationship between the loss-aversion coefficient and the proportion of loyal consumers is in the range of $\beta \in [0,1]$ and $\lambda \in [\beta^2/(2+\beta)^2, (\beta+\beta^2)/(2+\beta)^2]$, a vertically integrated manufacturer will choose to set $p_2 < p_1$, thereby maintaining high prices for retailer 1 with loyal consumers and thus earning high profits from loyal consumers, and inducing price-sensitive consumers to purchase from retailer 2. When the relationship is not in this range, the vertically integrated manufacturer uses retailer 2 as the "price benchmark" to motivate consumers to purchase from retailer 1. This leads to the Proposition 2.

Proposition 2. *The pricing strategy of the vertically integrated manufacturer depends on the relationship between the loss-aversion coefficient and the proportion of loyal consumers. Thus, when $\beta \in [0,1]$ and $\lambda \in [\beta^2/(2+\beta)^2, (\beta+\beta^2)/(2+\beta)^2]$, the price will be set at $p_2 < p_1$, and A-type consumers and B-type consumers will purchase from the offline shop and the online shop, respectively, in which case the two channels' equilibrium prices will be $p_1 = (2\lambda + \beta(1+\lambda))/((2+\beta)^2\lambda - \beta^2)$ and $p_2 = (2+\beta)\lambda/((2+\beta)^2\lambda - \beta^2)$, and the equilibrium profit will be $\pi_{vi} = \pi'''_{vi} = (1+\beta)\lambda/((2+\beta)^2\lambda - \beta^2)$. In other ranges, the price will be set at $p_2 > p_1$, and A-type consumers and B-type consumers will purchase from the offline shop, in which case the two channels' equilibrium prices will be $p_1 = 1/2$ and $p_2 = 1$, and the equilibrium profit will be $\pi_{vi} = \pi'_{vi} = (1+\beta(1-\lambda))/4$.*

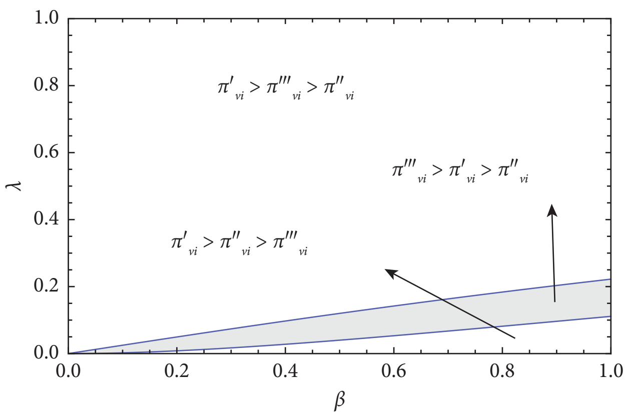

Figure 4: Equilibrium profit under centralized decision-making.

Figure 4 intuitively displays the equilibrium described in Proposition 2. In the blank area, the price is set at $p_2 > p_1$, and both A-type consumers and B-type consumers will purchase from the offline shop. The manufacturer has incentives to set a higher price for the offline shop, so as to stimulate online sales.

4. Results

When upstream manufacturers impose vertical restraints on downstream retailers, the equilibrium price and demand for the product in the downstream market becomes equal to the outcome under integration, which implies the disappearance of the double markup and the fact that the total profits of all firms are greater than the total profits of firms in the decentralized case. However, as vertical restraints affect consumer surplus, social welfare requires further analysis.

4.1. Comparison and Discussion. First, we assess the difference in the final market price of the product in the range of $\beta \in [0,1]$ and $\lambda \notin \in [\beta^2/(2+\beta)^2, (\beta+\beta^2)/(2+\beta)^2]$ (the first equilibrium of the centralized decision) in the two cases (the superscript VI indicates the solution under integration and SP indicates the solution when operating separately; these superscripts denote the same hereafter):

$$\Delta p_1 = p_1^{\mathrm{VI}} - p_1^{\mathrm{SP}} = -\frac{1}{4} < 0, \tag{7}$$

$$\Delta p_2 = p_2^{\mathrm{VI}} - p_2^{\mathrm{SP}} = \frac{2+3\beta}{8+8\beta} > 0. \tag{8}$$

From equations (7) and (8), we see that when the proportion of loyal consumers λ is too small or too large, the integrated manufacturer will abandon the online channel and use it as a price benchmark to stimulate offline sales by using the high price of the online channel.

Combining equations (7) and (8) yields

$$\left|p_1 - p_2\right|^{\mathrm{VI}} - \left|p_1 - p_2\right|^{\mathrm{SP}} = \frac{4+3\beta}{8+8\beta} > 0. \tag{9}$$

In the case of vertical restraints or vertical integration, the price gap between channels is expanded to promote consumer purchases. This gap decreases as the loss-aversion coefficient increases.

In the range of $\beta \in [0,1]$ and $\lambda \in [\beta^2/(2+\beta)^2, (\beta+\beta^2)/(2+\beta)^2]$, the gap between the final market prices of the two products is

$$\Delta p_1 = p_1^{\mathrm{VI}} - p_1^{\mathrm{SP}} = \frac{2\lambda + \beta(1+\lambda)}{(2+\beta)^2\lambda - \beta^2} - \frac{6+5\beta}{8+8\beta} > 0. \tag{10}$$

The reason that the integrated manufacturer will set higher prices in the offline channel is that with vertical integration, competition between the two channels is internalized, so setting high prices in the online channel can deprive loyal consumers of surplus and stimulate sales in the offline channel:

$$\Delta p_2 = p_2^{\mathrm{VI}} - p_2^{\mathrm{SP}} = \frac{\lambda(2+\beta)}{(2+\beta)^2\lambda - \beta^2} - \frac{3}{4}. \tag{11}$$

The signs of equation (11) depends on the specific range of λ. When $\lambda \in [\beta^2/(2+\beta), 3\beta^2/((2+\beta)-\beta^2)]$, we have $\Delta p_2 > 0$; when $\lambda \in [3\beta^2/((2+\beta)-\beta^2), (\beta+\beta^2)/(2+\beta)^2]$, we have $\Delta p_2 < 0$. The reason for this is that when λ is small, the integrated manufacturer values the benefits generated by the online channel more and sets the online price p_1 at a higher level, which in turn drives up p_2; as λ increases, p_1 will gradually decrease, while driving down p_2 and eventually yielding the case $\Delta p_2 < 0$.

By combining equations (10) and (11), we get

$$\left|p_1 - p_2\right|^{\mathrm{VI}} - \left|p_1 - p_2\right|^{\mathrm{SP}} = \frac{\beta\left(\lambda(2+\beta)^2 + 8(1+\beta) - \beta^2\right)}{8(1+\beta)\left(\lambda(2+\beta)^2 - \beta^2\right)} > 0. \tag{12}$$

In the equilibrium of vertical integration with $p_2 < p_1$, the price gap between channels is expanded to promote consumer purchases; however, unlike the equilibrium with $p_2 > p_1$, the channel price gap increases with the loss-aversion coefficient and decreases with the proportion of loyal consumers in the equilibrium with $p_2 < p_1$.

Proposition 3. *Compared to the market equilibrium under separate operation, integrated manufacturers have an incentive to expand the price gap between the two channels in either the $p_2 > p_1$ or the $p_2 < p_1$ equilibrium, thus promoting sales in the "primary" channel in the integrated equilibrium with $p_2 > p_1$, the primary sales channel is the offline channel, where the channel price gap decreases as the sensitivity to loss aversion increases; in the integrated equilibrium with $p_2 < p_1$, the primary sales channel is the online channel, where the channel price gap increases as the sensitivity to loss aversion increases.*

Second, the total sales Q^{VI} and Q^{SP} in both cases are compared to investigate the stimulative effect of the strategic channel price gap on total sales. In the integration equilibrium with $p_2 > p_1$, the difference in sales compared to the separation equilibrium is

$$Q^{VI} - Q^{SP} = \frac{(2 + 3\beta(1-\lambda))}{8} > 0. \quad (13)$$

The total sales differential is positive, and we know that $\partial\Delta Q/\partial\beta > 0$ and $\partial\Delta Q/\partial\lambda < 0$:in the integrated equilibrium with $p_2 > p_1$, the online channel sales are zero and used solely as a "price benchmark," so with an increase in the loss-aversion coefficient, the upstream manufacturer stimulates consumption by expanding the strategic channel price gap and thus exploiting consumers' loss aversion to increase the total sales and thereby enhancing the total channel profit. With an increase in the proportion of loyal consumers λ, the "price benchmark" role of the online channel weakens thus reducing the revenue expansion effect generated by expanding the channel price gap, so the sales differential decreases as the proportion of loyal consumers λ increases.

In the integration equilibrium with $p_2 < p_1$, the difference in sales compared to the separation equilibrium is

$$Q^{VI} - Q^{SP} = \frac{8\lambda + \beta\left(\beta(2+\beta) + 4\lambda - 2\beta\lambda(3+\beta) + (2+\beta)^2\lambda^2\right)}{8(2+\beta)^2\lambda - 8\beta^2} > 0. \quad (14)$$

The total sales differential remains positive, meaning that the total sales are always higher with vertical restraints. At this point, $\partial\Delta Q/\partial\beta > 0$ and $\partial\Delta Q/\partial\lambda < 0$: In the integration equilibrium with $p_2 < p_1$, the online channel will set a lower price, and with the enhancement of the loss-aversion coefficient, the additional utility from the high price of the offline channel will be strengthened, thus more strongly stimulating the sales of the offline channel, so $\partial\Delta Q/\partial\beta > 0$; as the proportion of loyal consumers λ increases, fewer consumers receive the additional utility of the "price benchmark," thus limiting the total demand of the integrated manufacturer, so the sales differential decreases as the proportion of loyal consumers increases.

4.1.1. Welfare Analysis.

From equations (7) and (8), it can be seen that in the equilibrium of vertical restraints with $p_2 > p_1$, the price of the offline shop decreases and the price of the online shop increases, so all consumers buy from the offline shop. Since the price of the offline shop is also lower than the price of the online shop in the separating equilibrium, the demand for all types of consumers is raised, and the total consumer utility is enhanced.

Equations (10) and (11) indicate that in the equilibrium of vertical restraints with $p_2 < p_1$, the price of the offline shop increases, and there is uncertainty about the price variation of the online shop. In this case, loyal consumers necessarily lose their surplus, but there is a uncertainty in the change of loss-averse consumers' surplus. When $\lambda \in [\beta^2/(2+\beta), 3\beta^2/((2+\beta)-\beta^2)]$ and $\Delta p_2 > 0$, but $\Delta p_1 > 0$ then, it will provide an additional utility to loss-averse consumers, so the surplus change for loss-averse consumers depends on the net effect of price changes in both channels. When $\lambda \in [3\beta^2/((2+\beta)-\beta^2), (\beta+\beta^2)/(2+\beta)^2$, and $\Delta p_2 < 0$, the superposition of the utility gains from $\Delta p_1 > 0$, and we obtain that loss-averse consumers' surplus is improved. To further compare consumer surplus in the equilibrium of vertical restraint case with $p_2 < p_1$ and in the separate operation equilibrium, the expression for consumer surplus can be shown as

$$CS^{VI} = \frac{\lambda(1+\beta)^2\left(4\lambda + \beta^2(1-\lambda)\right)}{2\left(\lambda(\beta+2)^2 - \beta^2\right)^2}, \quad (15)$$

$$CS^{SP} = \frac{\lambda\left(8 + 4\beta + \beta^2\right)}{128}. \quad (16)$$

Equation (15) minus equation (16) shows that the consumer surplus differential under vertical restraints and under separate operation is always positive within the parameter.

$$\Delta CS = CS^{VI} - CS^{SP} > 0. \quad (17)$$

Equation (17) shows that consumer surplus is always larger under the imposition of vertical restraints, meaning that the vertical restraint behavior of the upstream manufacturer increases consumer welfare. This leads to Proposition 4.

Proposition 4. *Compared to the case of separate operations, consumer surplus increases when vertical restraints are imposed by upstream manufacturers in both cases. As the total profit of the firm increases, social welfare also increases.*

Proposition 4 shows that when consumers are able to derive utility from the price gap, consumer surplus is improved in the vertical restraint case when the upstream manufacturer endogenizes the channel price gap, thus allowing consumers to derive additional utility from the price gap. In addition, the pricing decision in the separate operation case is a subset of the pricing set in this case when vertical coordination is achieved. Therefore, the overall profits of firms must increase when vertical restraint coordination is achieved, and total social welfare is improved.

The equilibrium solutions and differentials of all variables under decentralized and centralized decision-making are given in Table 3.

In contrast to previous studies, this article demonstrates that if consumers exhibit loss aversion under bounded rationality, the implementation of vertical restraints is beneficial to social welfare. Thus, the antitrust authority, which seeks to maximize social welfare, should not adopt the "per se illegal rule" on the vertical restraint behavior of firms but rather use the "rule of reason" to conduct a comprehensive analysis of market performance.

4.2. Sensitivity Analysis.

To verify the abovementioned theoretical model conclusion more intuitively, parameters are established to verify the model numerically.

In the equilibrium of vertical restraints with $p_2 > p_1$, the manufacturer's online channel is used solely as the "price benchmark." $\lambda = 2/5$ is set to compare the change in the channel price gap, overall profit, and consumer surplus. The variation in the channel price gap is shown in Figure 5, and the channel price gap in the equilibrium of vertical restraints

Table 3: Equilibrium solutions under decentralized and centralized decision-making and comparison.

Variable	Decentralized (SP)	Centralized 1 (VI) ($p_2 > p_1$)	Centralized 2 (VI) ($p_2 < p_1$)	Differential 1	Differential 2
Price					
Offline shop p_1	$3/4$	$1/2$	$(2\lambda + \beta(1+\lambda))/((2+\beta)^2\lambda - \beta^2)$	−	+
Online shop p_2	$(6+5\beta)/(8+8\beta)$	1	$((2+\beta)\lambda)/((2+\beta)^2\lambda - \beta^2)$	+	−
Price gap $\lvert p_1 - p_2 \rvert$	$\beta/(8+8\beta)$	$1/2$	$\beta/((2+\beta)^2\lambda - \beta^2)$	+	+
Demand					
Offline shop q_1	$\lambda/4$	$(1+\beta(1-\lambda))/2$	$(\lambda - \lambda(\beta + (2+\beta)\lambda))/((2+\beta)^2\lambda - \beta^2)$	+	−
Online shop q_2	$((2+\beta)(1-\lambda))/8$	0	$(\lambda(1-\lambda)(2+3\beta+\beta^2))/((2+\beta)^2\lambda - \beta^2)$	−	+
Total demand Q	$(2+\beta-\beta\lambda)/8$	$(1+\beta(1-\lambda))/2$	$(2\lambda(1+\beta))/((2+\beta)^2\lambda - \beta^2)$	+	+
Total profit	$(12+4\beta(4-\lambda)+5\beta^2(1-\lambda))/(64(1+\beta))$	$(1+\beta(1-\lambda))/4$	$((1+\beta)\lambda)/((2+\beta)^2\lambda - \beta^2)$	+	+
Consumer surplus	$(4+\beta(4+\beta)(1-\lambda))/128$	$(\beta(\beta+2)(1-\lambda)+1)/8$	$(\lambda(1+\beta^2(4\lambda+\beta^2(1-\lambda)))/(2(\lambda(\beta+2(\beta)^2-\beta^2)^2)$	+	+

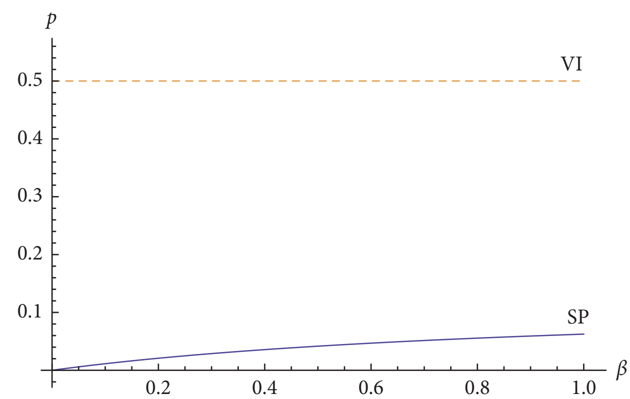

Figure 5: Channel price gap comparison (p2>p1).

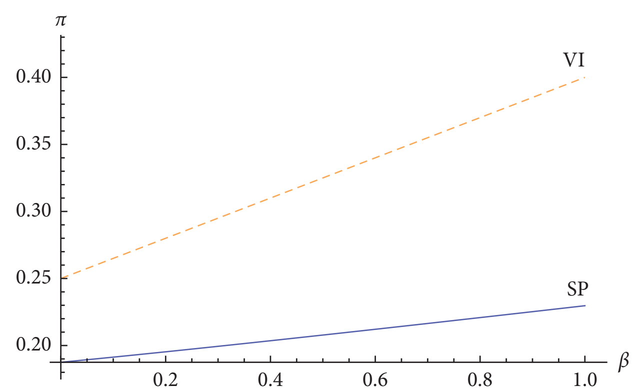

Figure 6: Profit comparison(p2>p1).

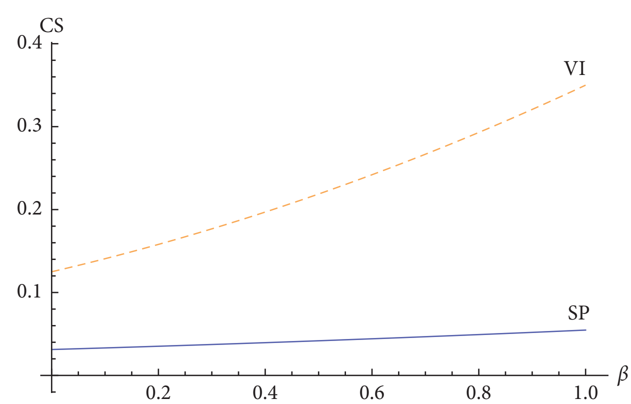

Figure 7: Consumer surplus comparison(p2>p1).

with $p_2 > p_1$ is larger than that in the separated equilibrium, and this price gap decreases with an increase in the loss-aversion coefficient.

Figure 6 shows an increase in the overall profit with vertical restraints, and the profit under vertical restraints is significantly higher than that in the separation equilibrium, and the profit difference increases with the increase in the loss-aversion coefficient β. This indicates that the "price benchmark" role of the offline channel increases with the increase in the loss-aversion coefficient β.

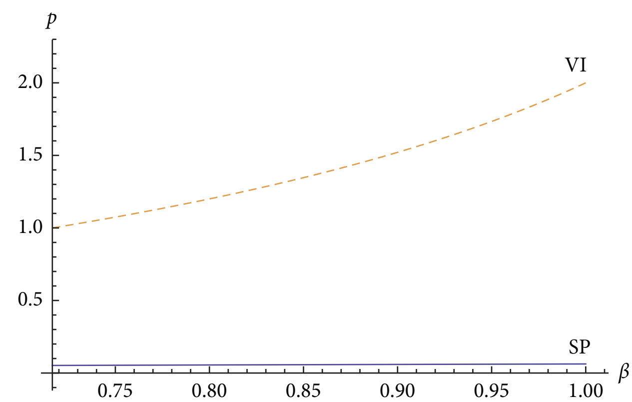

Figure 8: Channel price gap comparison(p2<p1).

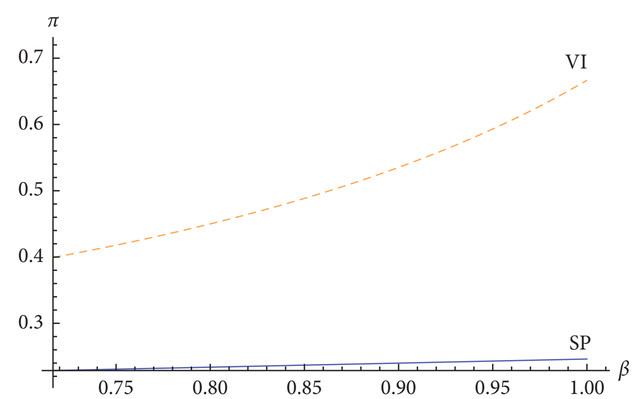

Figure 9: Profit comparison(p2<p1).

Figure 7 shows the increase in consumer surplus due to vertical restraints, and the consumer surplus is significantly higher under vertical restraints than under the separating equilibrium, and the difference in consumer surplus increases with the increase in the loss-aversion coefficient β. This indicates that the "price benchmark" is enhanced with the increase in β, thus increasing the overall profit and consumer surplus.

In the equilibrium of vertical restraints with $p_2 < p_1$, the manufacturer's offline channel is used to extract loyal consumer surplus, and the online channel is used to attract loss-averse consumers. By setting $\lambda = 1/6$, we compared the changes in the channel price gap, overall profit, and consumer surplus within the parameter range in the equilibrium of vertical restraints with $p_2 < p_1$. The change in the channel price gap is shown in Figure 8, and the channel price gap under the vertical restraint equilibrium is larger than that under the separated equilibrium; unlike the vertical equilibrium with $p_2 > p_1$, the difference between the two equilibrium expands with the increase in the loss-aversion coefficient β. The manufacturer that implements vertical restraints can sell using both channels, and they can enhance the purchase of disloyal consumers by increasing the price gap.

Figure 9 demonstrates the enhancement of overall profits due to vertical restraints, and profits under vertical restraints are significantly higher than those under the separation

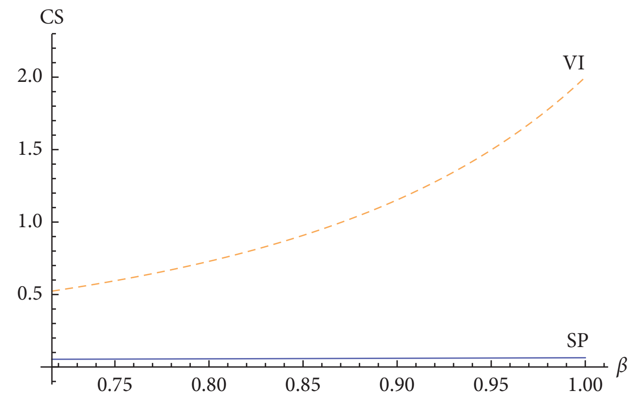

Figure 10: Consumer surplus comparison(p2<p1).

equilibrium, and the profit differential increases with the loss-aversion coefficient β; the profit differential in the equilibrium with $p_2 < p_1$ is greater than that in the equilibrium with $p_2 > p_1$ equilibrium because the two channels are used to serve different consumer types.

Figure 10 demonstrates the enhancement of consumer surplus due to vertical restraints, and consumer surplus under vertical restraints is significantly higher than that in the separated equilibrium, and the consumer surplus differential expands with the loss-aversion coefficient β. Again, because the two channels are used to serve different consumer types, the full use of the channel price gap leads to a significantly larger surplus differential under the equilibrium where $p_2 < p_1$ than under the equilibrium where $p_2 > p_1$.

5. Managerial Insights and Policy Implications

Under the influence of information technology, it has become more convenient for consumers to search and compare prices, so loss-averse consumers tend to look for the cheapest products. Moreover, retailers in online channels exploit this consumer psychology to prominently mark corresponding offline channels' prices on online sales pages for promotion. If the channel is not coordinated with vertical restraints, then this behavior is actually "free-riding" on the channel price gap. Online retailers use the price cues of offline shops to increase their consumers' psychological utility and thus promote product sales. On this basis, upstream manufacturers have an incentive to maximize total profits by internalizing the externalities of the channel price gap using vertical restraints such as resale price maintenance and two-part tariffs.

While manufacturers can use vertical restraints to internalize the effects of the channel price gap, their actions are prone to channel conflicts and related antitrust reviews if they do not pay attention to revenue sharing and specific measures for downstream retailers in their agreements. The Shanghai Municipal Development and Reform Commission's decided to impose administrative penalties on Chongqing Haier Home Appliance Sales Co., Ltd. Shanghai Branch for implementing minimum resale prices exactly because of complaints from Haier retailers. The "rule of reason" is applied to resale price maintenance in judicial practice. In recent years, resale price maintenance and other vertical restraint cases have become a major focus of Chinese antitrust authorities, so firms should be very cautious in using vertical restraints while recognizing the incentives behind them.

6. Conclusions

The main goal of this research study is to explain the phenomenon of online and offline price gaps and to present a mathematical framework for analyzing the effect of vertical restraints. This article investigates how firms use vertical restraints to endogenize the impact of the channel price gap on consumers when some consumers search for prices and exhibit loss aversion. Therefore, the main contribution of this article is to consider the role of consumers' bounded rationality in dual supply chain coordination. The comparative study also answers whether vertical restraints should be prohibited when consumers are loss averse.

The main results of this article are as follows:

(1) When the supply chain is not coordinated by the manufacturer, an online retailer can exploit consumers' loss aversion by using a higher offline price. The offline price acts as a reference price, and the channel price gap then offers extra utility to loss-averse consumers, thus stimulating sales in the online shop.

(2) When the supply chain is coordinated by a manufacturer, upstream manufacturers have an incentive to maximize total profits by internalizing the externalities of the channel price gap, using vertical restraints such as resale price maintenance and two-part tariffs. In this case, vertical restraints help reduce price gaps and increase sales.

(3) From the perspective of social welfare, the consumer surplus and total profits are significantly higher under vertical restraints. Therefore, when consumer loss aversion is considered, vertical restraint contracts are not anticompetitive, as found in previous studies.

While this article examines the effect of dual-channel coordination on market competition and social welfare when consumers are loss averse, it does not consider enough cases. There are several interesting topics for further research studies. The research can get closer to the real world by applying uncertainty in modeling [39, 40]. For example, the uncertainty of market demand or fuzzy network should be considered [36, 41], information asymmetry should be examined, and quality uncertainty and return policy cases should be explored. We also consider developing a dynamic model with interdependent demand [42, 43], and a stochastic model [44], which are worthy of future study.

Data Availability

The data used to support the findings of the study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Competitive Relief Supply Chain under the Uncertain Conditions

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Relief operations and planning to implement them are essential due to the unpredictability of natural disaster occurrences and their concomitant damages. The Crisis and Disaster Management Organization's responsibility is to execute plans, coordinate, control relief, and rescue operations to reduce the impacts and consequences of these disasters. Thus, this organization should attend to the struck regions' needs with their maximum power as soon as possible. This study has initially reviewed the latest available literature regarding the humanitarian supply chain to determine the research gap. Accordingly, in this research, a mathematical model with a leader-follower approach for relief delivery in the crisis response phase was designed, which took into account the policies of the country of Iran for the distribution of relief items. The amount of inventory of suppliers was also considered as uncertain. Then, to validate it, a numerical example was solved by the metaheuristic algorithm MOEA/D. The results indicated that the designed model is valid and the selected algorithm to solve it has an acceptable performance. Finally, some effective parameters were selected in the model and the sensitivity of the model was evaluated based on their changes.

1. Introduction

Natural disasters such as earthquakes, floods, hurricanes, and drought embroil different regions of the world every year and often hurt human lives and properties. Moreover, natural disasters are increasing due to factors like population growth and climate change, and the current facilities are insufficient [1]. More comprehensively, natural disasters are associated with potential long-term economic, environmental, financial, human, and social impacts. These unexpected and severe events hurt economic growth [2] and enhance the uncertainty and challenges for organizations [3]. From the management's perspective, the detrimental impacts of disasters treat societies over the years, and their financial and human costs are inevitable for the victims. However, decision-makers can reduce human recompense and mortalities by their exact, effective, quick, and up-to-date responses. The performance of humanitarian organizations in encountering natural disasters (such as earthquakes, floods, and hurricanes) and human factors (such as fire, environmental pollution, and war) should be assessed in different aspects to optimize the speed of operations, increase the flexibility of the services, and reduce the costs [4]. To this end, disaster management emphasizes planning, prioritization, and decision-making in relief operations [5]. Hence, managing disasters and crises is divided into several steps or phases (commonly included in predisaster and postdisaster phases). Predicting probable properties and lives recompenses and providing preparation programs to reduce the impacts of disasters through improving humanitarian logistics and emergency services are carried out in the predisaster step. In contrast, the postdisaster step comprises measures to respond to the disasters' recompenses [6]. The mentioned two steps are categorized into four steps for considering more details. The first step is the required measures for preventing a disaster and reducing its disastrous impacts. The second step is preparation measures, including planning manners in society to respond to recompenses quickly. The third step is the response, including utilizing emergency plans and allocated resources to the quick rescue of the victims, providing medical care and treatment services, sending required services and products to injured regions, and helping prevent infrastructural and environmental recompenses. The fourth step, the final recovery, includes measures for returning to the normal situation [7].

Based on the discussed topics here, the purpose of this research is to design a mathematical model for planning and organizing relief operation during an earthquake, so as to minimize the costs, harmful environmental effects, and the number of unresponded demands. Based on this, we will first introduce the parameters and decision variables, then we will present the mathematical model, and after that we will solve the model using MOEA/D metaheuristic algorithm, and finally, we will analyze the sensitivity of some parameters.

2. Survey on Related Work

Maharjan and Hanaoka [8] introduced a multiobjective location-allocation model for supplying and distributing relief. Their proposed model considers parameters' inexact and time-varying nature and time-varying envelopment. Results indicated the time, location, and the number of temporary relief centers that should be created. Besides, how the resources should be allocated is revealed in their results. Salehi and Jabarpour [9] assessed a multiobjective model for locating, distributing, and routing multiperiod problems, considering evacuating injured and homeless individuals as well as fuzzy paths in relief services. Notably, the fuzzy approach is used to create uncertain conditions. Jaggi and Singh [10] designed an inventory relief supply chain model for relief product distribution to determine the optimal number of central distribution and relief centers. In this study, a center is considered for relief product distribution. Finally, the model is revised to optimize the total cost of relief operations. It is worth noting that an algorithm is proposed to find the model's optimal solution. In another study, Zahedi et al. [11] developed two innovative approaches for designing a relief supply chain network using the Internet of Things (IoT) to examine several suspect cases during pandemic (e.g., COVID-19). Their first approach (prioritizing approach) minimizes the maximum response time of ambulances. Moreover, their second approach (allocation approach) minimizes the total crisis response time. Each approach is examined and proved using many experimental problems and one real problem in Iran. Eventually, both of these approaches are proposed. The confirmed cases are reduced by 34.54%, implementing the proposed model based on the IoT in three continuous weeks. Saatchi et al. [12] presented a relief supply chain network in two phases (predisaster and postdisaster). They designed a relief supply chain in two directions (forward and backward directions). Eventually, they solved the model in extensive dimensions using the nondominated sorting genetic algorithm (NSGA-II). Manopiniwes and Irohara [13] studied creating an integrated humanitarian supply chain management model to respond to floods. Their study discusses the interaction among various factors in the relief supply chain during an optimal framework. For this purpose, a model is created to control the total flow of supply distribution, evacuation planning, and relief resources and optimally formulate the routing of the temporary storehouse centers. Finally, a routing model for temporary storehouse problems (created for such disasters) is proposed. Meanwhile, the proposed model is formulated using a multiperiod approach. Mamashli et al. [14] studied the allocation routing problem in the crisis reaction phase. They proposed a scenario-based multiobjective planning model for examining the sustainable allocation of routing problem to cover factors such as sustainability and resilience (rarely considered in previous studies). Moreover, they proposed their model based on the concept of justice, and its purposes are minimizing the travel time, total environmental consequences, and losing total demand. Finally, they proposed a hybrid approach based on a multioptions objective planning method and heuristic solution algorithm to solve the problem in a reasonable time, given the complexity of the model. Vahdani et al. [15] presented a two-objective optimization model to plan a humanitarian regional logistics network. The mentioned model has been considered the extensive range of simultaneous decision-making regarding allocation of emergency facilities location, reclassification, sharing services, and vehicle routing. The two types of open and closed vehicle routing problems are used for ground and aerial routing. Due to the undetermined nature of the disaster, the cost, supply, and demand parameters are considered uncertain in their study. Finally, a hybrid robust optimization model is proposed. The validity of this model is examined in a real study case. Gutierrez et al. [16] assessed the routing problem using automobile routing problem with cumulative capacity. All related constraints are discussed and presented, given the various features of the problem during the time. Additionally, the analysis of related studies regarding solution algorithms and benchmark samples is provided in this study. Finally, some suggestions are provided for future studies in this regard. Emami et al. [17] debated a new term "secondary disaster" recently introduced regarding the consequences of disasters threatening human lives. All hurt regions may encounter secondary disasters due to natural disasters. However, this fact is generally ignored and can amplify the disasters' consequences. Therefore, they examined the designing of relief resource supply chain to reduce human and economic consequences of natural disasters and presented optimal relief and rescue operations, given the probable occurrence of primary and secondary disasters. Moreover, a single-objective planning mixed nonlinear integer planning model is presented to meet the demand for relief products, victims rescue, and evacuation of injured people, given the dynamic nature of secondary impacts and requiring continuous updating of the relief management process. The mentioned model minimizes the demand in primary and secondary crisis conditions, transportation time, transportation costs, and unmet demand based on the region's prioritization. Also, the priority of demand scores is defined based on the unmet needs value and the period of privation from relief products and services. According to this perspective, the demand regions are prioritized, and unmet needs are minimized. A hybrid genetic algorithm (GA) approach and rolling-horizon planning are introduced to solve the model as the problem of the study is related to the classification of NP-hard problems. Eventually, the proposed algorithm is implemented on available datasets based on the case study, which indicates the high quality of the solution method in terms of the quality of solution and computational time. Modiri et al. [18] introduced a multiobjective mixed-integer mathematical planning model for designing relief product distribution networks in disaster relief logistics. The first objective function minimizes the total network costs and is divided into two parts: (1) relief costs (transportation, inventory, and fixed facilities costs) and (2) social costs (privation costs). The second objective function minimizes the produced pollution by the network. According to investigating the relevant literature, they declared that this is the first study that proposes a robust fuzzy optimization approach for the problem of designing the relief products distribution network, considering the environmental (CO_2 emissions), social (privation cost), and economic consequences under reliability and uncertainty. The multiobjective model is solved using multioption objective planning. A case study based on real data (flood in Sari Province in 2019) is evaluated to demonstrate the model's validity. The proposed model allows managers and decision-makers to adopt strategic and tactic decisions with the lowest cost and time. Moreover, they can enhance the structure of distribution networks and inventory and reduce victims' dissatisfaction. Ozen and Krishnamurthy [19] explained that the distribution of relief products for victims is one of the critical activities in reacting to disasters. Due to the dynamic changes in victims' requirements and postcrisis conditions, the distribution of relief products is challenging. They have modeled distribution operations. So that products such as tarps and blankets are distributed among the victims in various temporary distribution regions called relief centers by volunteers. They examined the impacts of victims' mobility on the distribution performance. Thus, they modeled every relief center as a queue and distribution operations as a generalized queue network (Gelenbe network). Meanwhile, the product form solutions are examined for the generalized queue network model; a new product form is proved for generalized queue networks with classified batch signals and transmission under particular conditions. They used this result to develop product form approximations applied to a wide range of settings. Then, they applied a generalized queue network model for a case study from relief distribution data of Nepal earthquakes and determined the impact of victims' mobility on the network performance. Mahmoodi et al. [20] declared that humanitarian supply chain management differs from commercial supply chains. Thus, the purpose of humanitarian supply chains is to minimize the time of reacting to a disaster. Contrary, the purpose of the commercial supply chain is the maximization of profit. Hence, they developed a relief chain structure, which includes emerging technologies in humanitarian provision in two steps (preparation and reaction steps). They sought to maximize the total demand covered by additive manufacturing and distribution centers and the total real weight allocated to drones. Eventually, the proposed model is solved using three methods, including one exact method and two metaheuristic methods. Based on the implementation results, the performance of the nondominated ranking genetic algorithm is better in finding optimal solutions. After solving the model with Cuckoo optimization algorithm (COA) and comparing the results with GAMS software results, the genetics algorithm is better than other options. Hashemi et al. [21] declared that there are still vital and fundamental challenges to optimizing emergency medical services, despite the extensive research and efforts in this regard over the last four decades. The experienced operational problems throughout the implementation of the proposed model led to novel concerns and the development of other models. Therefore, they examined the optimal location of emergency medical centers to present quicker and more efficient care. They sought to propose a mathematical model for the location of medical emergency centers aiming to increase the quality and quantity of demand coverage. Then, the behavior of the model is analyzed by defining numerical examples. The model is solved with GAMS software in small dimensions. The model is calculated in large dimensions using a metaheuristic algorithm by genetics algorithm, based on its NP-hard nature. Eventually, the results of the figures are compared with each other. According to the results, GAMS software's ability to solve the problem is lost with enhancing the dimensions of the problem; the time of solving the problem is reduced using genetics algorithms compared to GAMS software. Finally, contour lines are used for data analysis in a numerical example. The potential points for emergency medical services followed these lines and performed as the demand points. The accuracy of the model is proved with different parameters. Consequently, their proposed model can respond to medical emergency service demands and determine the optimal location of medical emergency care facilities. More details about survey on related work are shown in Table 1.

3. Research Gap

Based on the above table and considering the examined scopes of previous studies, the considered scopes of the present study are more extensive and examine the considered problem from different perspectives. Also, in the current research, the humanitarian supply chain has been organized locally and in adherence to the policies of the Crisis Management Organization of Iran; accordingly, all public aid and purchased relief items are handed over to the

Table 1: Survey on related work.

Author(s)	Year	Studied scope			Studied phase				Type of goal				Problem features					Solving method	
		Locating, routing, and transportation	Competitiveness	Uncertainty	Preparation	Prevention	Response (reaction)	Reconstruction	Economic	Social	Environmental	Time minimization	Multiproducts	Multiple transportation system	Multiperiod	Single-objective	Multiobjective	Exact	Heuristic
Maharjan&Hanaka	2020	*		*			*			*		*					*		*
Salehi &Jabbarpour	2020	*		*			*			*		*					*		*
Jaggi& Singh	2020	*					*		*							*			*
Zahedi et al.	2021	*					*					*				*			*
Madani-Saatchi et al.	2021	*			*		*		*	*							*		*
Manopiniwes&Irohara	2021	*					*		*						*	*			*
Mamashli et al.	2021	*		*			*		*	*	*	*					*		*
Vahdani et al.	2022	*		*			*		*					*			*		*
Corona-Gutierrez et al.	2022	*					*		*					*		*			*
Emami et al.	2022	*					*		*	*				*		*			*
Modiri et al.	2022	*		*			*		*	*	*	*					*		*
Ozen& Krishnamurthy	2022	*					*		*				*			*			*
Mahmoodi et al.	2022	*			*		*		*	*		*		*			*	*	*
Hashemi et al.	2022	*					*					*				*			*
Present study			*	*			*		*	*	*	*	*	*	*		*	*	

government, which, in turn, will ultimately decide on the quantity and modality of distributing them among the different involved organizations in the relief process. In addition, based on the level of response to the demand in each phase, nonprofit organizations that have cooperated in the distribution process will be provided with an incentive.

3.1. Problem Statement. The occurrence of natural disasters, particularly earthquakes, has uncertain nature. Hence, examining conditions and complete preparation in the reaction phase is very important and needs particular attention. Besides, reducing economic, environmental, and mental consequences is essential, needing deep examination and effective and logical solutions [22]. The proper and effective distribution of products and relief services after a disaster occurrence is critical among the mentioned items [23].

Therefore, a relief supply chain with triplet levels is introduced in this phase. According to Figure 1, in the first level, the supply centers are created permanently far from the disaster location to reduce costs and detrimental environmental consequences (due to relief measures, which are responsible for supplying and sending different types of relief products to distributors). At the second level, distribution centers (public and private) in hurt locations maximize the response temporarily to injured needs. Eventually, demand points are present as the final receiver of relief products.

3.2. Assumptions

(1) The inventory of the suppliers is considered to be uncertain (fuzzy).

(2) The costs of supplying and maintaining the products for suppliers have been overlooked.

(3) The costs of establishing distribution centers have been overlooked given the nature of public and private distributors' establishment (temporary).

(4) The model is multiproduct.

(5) The model is multiperiod.

(6) Various transportation systems (land, marine, and aerial) have been considered.

(7) The possibility of a secondary disaster has not been considered.

(8) The relief products demanded by the distributors (private and public) can be obtained from several supply centers.

(9) Given the diversity of the transportation system, vehicles are assumed to be available in diverse forms, adequate numbers, and sufficient capacity.

(10) The private distribution centers will receive financial incentives from the suppliers per response level (this is the difference between private distribution centers). Meanwhile, the speed of private distributors (the response time to demand) is more than public distributors regarding response to demand.

(11) The transportation costs and other related costs are similar for private and public distributors, as they provide services together.

This study tries to increase the coincidence degree of the model with real conditions considering logical conditions to design the model.

Optimizing the time and efficiently providing services are critical in the humanitarian supply chain. Hence, the multiplication of supply chain levels leads to the reduction of efficiency and extends the total time of the process. Thereby, the supply chain set does not perform properly.

Notably, relief products have high diversity. Hence, the studied model is designed in terms of multiproducts. According to the information regarding supply centers, these centers are used as gyms, storehouses, etc., in emergency cases. The supply centers can earn incomes by this utilization change; hence, this study ignores the costs of supply centers.

The sets and indices are as follows:

O the set of relief services represented by o indices; $o \in O$.

P the set of periods represented by p indices; $p \in P$.

I: the set of supply centers represented by i indices; $i \in I$.

J: the set of public and private distribution centers represented by j and j' indices; $(j \cup j') \in J$.

K the set of demand centers represented by k indices; $k \in K$.

R: the set of transportation represented by $r; r \in R$.

3.3. Parameters

t_{ijr}^{po} is the average delivery time spent on relief service o from supply center i to distribution center j (public) using transport method r over the p period.

$t_{ij'r}^{'po}$ is the average delivery time on relief service o from supply center i to distribution center (private) j' using transport method r over the p period.

$t_{jkr}^{''po}$ is the average delivery time on relief service o from supply center j to demand center (public) k using transportation method r over the p period.

$t_{j'kr}^{'''po}$ is the average delivery time on relief service o from supply center j' to demand center (private) k using transportation method r over the p period.

G_{ijr} is the CO_2 emission to deliver relief services from supply center i to distribution center j (public) using transportation method r per hour.

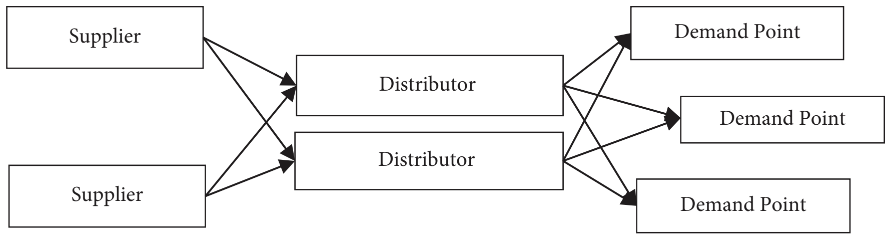

Figure 1: Levels of the proposed supply chain model.

$G'_{ij'r}$ is the CO_2 emission to deliver relief services from supply center i to distribution center j' (private) using transportation method r per hour.

G_{jkr}'' is the CO_2 emission to deliver relief services from supply center j to demand center k (public) using transportation method r per hour.

$G''_{j'kr}$ is the CO_2 emission to deliver relief services from supply center j' to demand center k (private) using transportation method r per hour.

S^{o}_{ijr} is the costs of delivering relief service o from supply center i to distribution center j (public) using transportation method r per unit.

$S'^{o}_{ij'r}$ is the costs of delivering relief service o from supply center i to distribution center j' (private) using transportation method r per unit.

S''^{o}_{jkr} is the costs of delivering relief service o from supply center j to demand center k (public) using transportation method r per unit.

$S'''^{o}_{j'kr}$ is the costs of delivering relief service o from supply center j' to demand center k (private) using transportation method r per unit.

$\widetilde{Q_i^{po}}$ is the inventory of relief service o at supply center i over the uncertain p period.

D^{po}_{j} is the expected value of relief service o at supply center j (public) over the p period.

$D'^{po}_{j'}$ is the expected value of relief service o at supply center j' (private) over the p period.

D''^{po}_{k} is the expected value of relief service o at demand center k over the p period.

w^{p}_{j} is the weighted value of distribution center j (public) over the p period based on damage severity.

$w'^{p}_{j'}$ is the weighted value of distribution center j' (private) over the p period based on damage severity.

w''^{p}_{k} is the weighted value of demand center k over the p period based on damage severity.

φ^{po}_{j} is the acceptable level of receiving relief service o in distribution center j (public) over the p period.

$\varphi'^{po}_{j'}$ is the acceptable level of receiving relief service o in distribution center j' (private) over the p period.

φ''^{po}_{k} is the acceptable level of receiving relief service o in demand center k over the p period 3.

δ^{o}_{k} is the risk coefficient of waste related to disaster per thousand units of relief service o on the environment.

π is the risk coefficient of carbon dioxide emissions per kilogram on the environment.

U^{o} is the conversion coefficient of relief service o to waste.

$B^{po}_{j'k}$ is The incentives received value by distribution center j' (private) for the percentage demand of converting relief services o over the p period.

T is the total available time.

3.4. Decision Variables

x^{po}_{ijr} is the real value of relief service o provided by supply center i to distribution center j (public) using transportation method r over the p period.

$x'^{po}_{ij'r}$ is the real value of relief service o provided by supply center i to distribution center j' (private) using transportation method r over the p period.

x''^{po}_{jkr} is the real value of relief service o provided by supply center i to demand center j (public) using transportation method r over the P period.

$x'''^{po}_{j'kr}$ is the real value of relief service o provided by supply center i to demand center j' (private) using transportation method r over the p period.

4. Mathematical Model

$$\min_{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}} \sum_{o\in O}\sum_{p\in P}\left(4-\left(\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} w_j^p \times \frac{x_{ijr}^{po}}{D_j^{po}} + \sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} w_{j'}^{'p} \times \frac{x_{ij'r}^{'po}}{D_{j'}^{'po}}\right) - \left(\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} w_k^p \times \frac{x_{jkr}^{''po}}{D_k^{''po}} + \sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} w_k^{''p} \times \frac{x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right), \tag{1}$$

$$\begin{aligned}
\min_{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}} & \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} \pi G_{ijr} \times t_{ijr}^{po} \times x_{ijr}^{po} + \sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} \pi G_{ij'r}{}' \times t_{ij'r}^{'po} \times x_{ij'r}^{'po}\right) \\
&+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} \pi G_{jkr}'' \times t_{jkr}^{''po} \times x_{jkr}^{''po}\right. \\
&\left.+ \sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} \pi G_{j'kr}'' \times t_{j'kr}^{'''po} \times x_{j'kr}^{'''po}\right) \\
&+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} \delta_k^o \times U^o \times x_{jkr}^{''po}\right. \\
&\left.+ \sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} \delta_k^o \times U^o \times x_{j'kr}^{'''po}\right).
\end{aligned} \tag{2}$$

$$\begin{aligned}
\min_{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}} & \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} S_{ijr}^{o} \times x_{ijr}^{po}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} S_{ij'r}^{'o} \times x_{ij'r}^{'po}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} S_{jkr}^{''o} \times x_{jkr}^{''po}\right) \\
&+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} S_{j'kr}^{'''o} \times x_{j'kr}^{'''po}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} B_{j'k}^{po} \times \left(w_k^{''p} \times \frac{x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right).
\end{aligned} \tag{3}$$

Subject to:

$$\left(\sum_{j\in J}\sum_{r\in R} x_{ijr}^{po} + \sum_{j'\in J}\sum_{r\in R} x_{ij'r}^{'po}\right) = \widetilde{Q_i^{po}} \quad \forall i \in I,\ p \in P,\ o \in O, \tag{4}$$

$$\sum_{i\in I}\sum_{r\in R} x_{ijr}^{po} \le D_j^{po} \quad \forall j \in J,\ p \in P,\ o \in O. \tag{5}$$

$$\sum_{i\in I}\sum_{r\in R} x_{ij'r}^{'po} \le D_{j'}^{po} \quad \forall j' \in J,\ p \in P,\ o \in O. \tag{6}$$

$$\sum_{i\in I}\sum_{r\in R} x_{ijr}^{po} \ge \left[\varphi_j^{po} D_j^{po}\right] \forall j \in J, p \in P, o \in O. \tag{7}$$

$$\sum_{i\in I}\sum_{r\in R} x_{ij'r}^{'po} \ge \left[\varphi_{j'}^{'po} D_{j'}^{'po}\right] \quad \forall j' \in J,\ p \in P,\ o \in O. \tag{8}$$

$$\left(\sum_{i\in I}\sum_{r\in R} t_{ijr}^{po} + \sum_{i\in I}\sum_{r\in R} t_{ij'r}^{po}\right) + \left(\sum_{k\in K}\sum_{r\in R} t_{jkr}^{''po} + \sum_{k\in K}\sum_{r\in R} t_{j'kr}^{'''po}\right) \le T \forall (j, j') \in J, p \in P, o \in O, \tag{9}$$

$$x_{ijr}^{po}, x_{ij'r}^{'po} \text{ are non-negative integer variables } \forall i \in I, (j, j') \in J, r \in R, p \in P, o \in O. \tag{10}$$

$$\begin{aligned}
\max_{x_{jkr}^{''po}, x_{j'kr}^{'''po}} & \left(\sum_{o\in O}\sum_{p\in P}\sum_{k\in K}\sum_{j\in J}\sum_{r\in R} \frac{\left(w_k^{''p} \times x_{jkr}^{''po}\right)}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)}\right) \\
&+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{k\in K}\sum_{j'\in J}\sum_{r\in R} \frac{\left(w_k^{''p} \times x_{j'kr}^{'''po}\right)}{\left(D_k^{''po} \times t_{j'kr}^{'''po}\right)}\right).
\end{aligned} \tag{11}$$

Subject to:

$$\left(\sum_{k\in K}\sum_{r\in R} x''^{po}_{jkr} + \sum_{k\in K}\sum_{r\in R} x'''^{po}_{j'kr}\right) = \left(\sum_{i\in I}\sum_{r\in R} x^{po}_{ijr} + \sum_{i\in I}\sum_{r\in R} x'^{po}_{ij'r}\right) \quad \forall (j, j') \in J,\ p \in P,\ o \in O. \tag{12}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x''^{po}_{jkr} + \sum_{j'\in J}\sum_{r\in R} x'''^{po}_{j'kr}\right) \le D''^{po}_{k} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{13}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x''^{po}_{jkr} + \sum_{j'\in J}\sum_{r\in R} x'''^{po}_{j'kr}\right) \ge \left[\varphi''^{po}_{k} D''^{po}_{k}\right] \quad \forall k \in K,\ p \in P,\ o \in O. \tag{14}$$

$$\sum_{j\in J}\sum_{r\in R} t''^{po}_{jkr} \ge \sum_{j'\in J}\sum_{r\in R} t'''^{po}_{j'kr} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{15}$$

$$x''^{po}_{jkr}, x'''^{po}_{j'kr} \text{ are non-negative integer variables} \quad \forall (j, j') \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{16}$$

Equation (1) (as the first objective function) minimizes the weighted rate of unmet demand for all periods. Equation (2) is the second objective function of the model in this section, aiming to reduce the detrimental environmental consequences of CO_2 emissions and waste. Equation (3) is introduced to minimize the applied costs to the supply chain. Equation (4) ensures that all suppliers' inventory is delivered to distributors (public and private) in each period. Equation (5) demonstrates that the demand of public distributors is not completely met in every period. Equation (6) demonstrates that the demand of private distributors is not completely met in every period. Equation (7) establishes fair conditions from public distributors as the minimum required demand. Equation (8) establishes fair conditions from private distributors as the minimum required demand. Equation (9) tries to prevent surpassing each period's total time from the standard determined time. Equation (10) represents the decision variables of the high-level problem.

Equation (11) is considered an objective function of low-level and indicates the maximization of the weighted percentage of met demand value in the entire period. Equation (12) demonstrates the balance in each distribution center (public and private) for each period. Equation (13) determines the unmet demand in each period. Equation (14) determines the fair conditions in each period. Equation (15) demonstrates that the total time of relief products and service distribution by private distribution centers is shorter than public distribution centers in each period. Equation (16) demonstrates the decision variables of the low-level problem.

4.1. Problem-Solving Approach. Two-level planning is a specific type of multilevel planning. In these models, a subset of the high-level variables is dependent on the solution of the low-level variables. The model is thus solved as follows.

The first step: formulation of the integer, two-level, and fuzzy three-objective programming model.

According to equation (4), the problem is under uncertain conditions. Thus, the model is made certain at this step. For this purpose, equation (4) is rewritten as follows:

$$\left(\sum_{j\in J}\sum_{r\in R} x^{po}_{ijr} + \sum_{j'\in J}\sum_{r\in R} x'^{po}_{ij'r}\right) = E\left(\widetilde{Q^{po}_{i}}\right) \quad \forall i \in I,\ p \in P,\ o \in O, \tag{17}$$

where $E(\widetilde{Q^{po}_{i}}) = (Q^{po}_{iL} + 2Q^{po}_{iH} + Q^{po}_{iU})/4$. Q^{po}_{iL} and Q^{po}_{iH} are the pessimistic and optimistic high and low values of inventory, respectively, and Q^{po}_{iU} is the most probable value [25].

The second step is the creation of the low-level dual problem.

The dual theory is used at this step to form the low-level dual problem. It must be noted that if variables x^{po}_{ijr} and $x'^{po}_{ij'r}$ are constant, the low-level problem can be considered a common transportation problem. Moreover, equation (16) concerning the decision variables of the low-level problem can be reduced as $x''^{po}_{jkr}, x'''^{po}_{j'kr} \ge 0$. For this purpose, $b^{po}_{j}, c^{po}_{k}, d^{po}_{k}, e^{po}_{k}$ are introduced to represent dual variables from equations (12) to (15). As a result, the dual problem related to low-level is given as follows:

$$\begin{aligned}\min_{\substack{b^{po}_{j}, c^{po}_{k},\\ d^{po}_{k}, e^{po}_{k}}} & \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{i\in I}\sum_{r\in R} x^{po}_{ijr} \times b^{po}_{j}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{i\in I}\sum_{r\in R} x'^{po}_{ij'r} \times b^{po}_{j'}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{k\in K} D''^{po}_{k} \times c^{po}_{k}\right) \\ & + \left(\sum_{o\in O}\sum_{p\in P}\sum_{k\in K}\left(-\left[\varphi^{po}_{k} \times D''^{po}_{k}\right]\right) \times d^{po}_{k}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R}\left(-t'''^{po}_{j'kr}\right) \times e^{po}_{k}\right).\end{aligned} \tag{18}$$

Subject to:

$$\left(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po}\right) \geq \frac{w_k^{''p}}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)} \tag{19}$$

$\forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O.$

$$\left(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po}\right) \geq \frac{w_k^{''p}}{\left(D_k^{''po} \times t_{j'kr}^{'''po}\right)} \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{20}$$

$$b_j^{po}, b_{j'}^{po} \text{urs} \quad \forall (j, j') \in J,\ p \in P,\ o \in O. \tag{21}$$

$$c_k^{po} \geq 0 \quad \forall k \in K,\ p \in P,\ o \in O. \tag{22}$$

$$d_k^{po} \geq 0 \quad \forall k \in K,\ p \in P,\ o \in O. \tag{23}$$

$$e_k^{po} \geq 0 \quad \forall k \in K,\ p \in P,\ o \in O. \tag{24}$$

Equation (18) is the objective function of the low-level dual problem. Equations (19) to (24) are the constraints of the low-level dual problem (make the solution space of dual problem).

The third step: the M_1 model is converted into a single-level model with nonlinear equations (M_2).

$$\min_{\substack{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po} \\ b_j^{po}, b_{j'}^{po}, c_k^{po}, d_k^{po}, e_k^{po}}} \sum_{o\in O}\sum_{p\in P}\left(4 - \left(\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} w_j^p \times \frac{x_{ijr}^{po}}{D_j^{po}} + \sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} w_{j'}^{'p} \times \frac{x_{ij'r}^{'po}}{D_{j'}^{'po}}\right) - \left(\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} w_k^{''p} \times \frac{x_{jkr}^{''po}}{D_k^{''po}} + \sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} w_k^{''p} \times \frac{x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right). \tag{25}$$

$$\begin{aligned}\min_{\substack{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}, \\ b_j^{po}, b_{j'}^{po}, c_k^{po}, d_k^{po}, e_k^{po}}} &\left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} \pi G_{ijr} \times t_{ijr}^{po} \times x_{ijr}^{po} + \sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} \pi G_{ij'r}' \times t_{ij'r}^{'po} \times x_{ij'r}^{'po}\right) \\ &+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} \pi G_{jkr}'' \times t_{jkr}^{''po} \times x_{jkr}^{''po} + \sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} \pi G_{j'kr}'' \times t_{j'kr}^{'''po} \times x_{j'kr}^{'''po}\right) \\ &+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} \delta_k^o \times U^o \times x_{jkr}^{''po} + \sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} \delta_k^o \times U^o \times x_{jkr}^{'''po}\right),\end{aligned} \tag{26}$$

$$\begin{aligned}\min_{\substack{x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}, \\ b_j^{po}, b_{j'}^{po}, c_k^{po}, d_k^{po}, e_k^{po}}} &\left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R} S_{ijr}^{o} \times x_{ijr}^{po}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R} S_{ij'r}^{'o} \times x_{ij'r}^{'po}\right) \\ &+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} S_{jkr}^{''o} \times x_{jkr}^{''po}\right) + \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} S_{j'kr}^{'''o} \times x_{j'kr}^{'''po}\right) \\ &+ \left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} B_{j'k}^{po} \times \left(w_k^{''p} \times \frac{x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right).\end{aligned} \tag{27}$$

Subject to:

$$x_{jkr}^{''po} \times \frac{\left(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right)}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)} = 0 \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{28}$$

$$x_{j'kr}^{'''po} \times \frac{\left(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right)}{\left(D_k^{''po} \times t_{j'kr}^{'''po}\right)} = 0 \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{29}$$

$$c_k^{po} \times \left(D_k^{po} - \left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po} \right) \right) = 0 \quad \forall k \in K,\ p \in P,\ o \in O, \tag{30}$$

$$d_k^{po} \times \left(\left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po} \right) - \left[\varphi_k^{''po} \times D_k^{''po} \right] \right) = 0 \quad \forall k \in K,\ p \in P,\ o \in O. \tag{31}$$

$$e_k^{po} \times \left(\sum_{j\in J}\sum_{r\in R} t_{jkr}^{''po} - \sum_{j'\in J}\sum_{r\in R} t_{j'kr}^{'''po} \right) = 0 \quad \forall k \in K,\ p \in P,\ o \in O. \tag{32}$$

$$x_{jkr}^{''po} \geq 0 \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{33}$$

$$x_{j'kr}^{'''po} \geq 0 \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{34}$$

Including equations (5)-(10), (12)-(15), (17), and (19)-(24).

Equations (25)-(27) are the objective functions of the model that have transformed into a single-level (M_2). Further, equations (5)-(10), (12)-(15), (17), (33), and (34) specify the feasible region of the primal problem (M_0) while equations (19)-(24) specify the feasible region of the dual problem. Equations (28)-(32) create sufficient conditions to obtain the optimal value for the primal-dual problems.

As a result, the M_1 three-objective two-level integer planning model converts to a nonlinear mathematical optimization model, single-level and three-objective, and M_2 with $x_{ijr}^{po}, x_{jkr}^{''po}, x_{ij'r}^{'po}, x_{j'kr}^{'''po}, b_j^{po}, b_{j'}^{po}, c_k^{po}, d_k^{po}, e_k^{po}$ variables. It must be mentioned that solving the converted model is still challenging since equations (28)-(32) are nonlinear.

The fourth step is strategies of converting nonlinear constraints into linear constraints.

This step uses binary auxiliary variables to make equations (28)-(32) linear. The N parameter is defined as a large positive constant and $\theta_{jkr}^{po} \in \{0,1\}$ is defined as the auxiliary variable for constraint (28). Considering equations (19) and (33), we will have the following: $(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p})/(D_k^{''po} \times t_{jkr}^{''po}) \geq 0$ and $x_{jkr}^{''po} \geq 0$. Consequently, equations (35) and (36) are added as follows:

$$x_{jkr}^{''po} \leq N \times \left(1 - \theta_{jkr}^{po}\right) \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{35}$$

$$\frac{\left(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right)}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)} \leq N \times \theta_{jkr}^{po} \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{36}$$

Similarly, considering equations (20) and (34), we will have the following: $(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p})/(D_k^{''po} \times t_{j'kr}^{'''po}) \geq 0$ and $x_{j'kr}^{'''po} \geq 0$. Equations (37) and (38) are thus added as follows:

$$x_{j'kr}^{'''po} \leq N \times \left(1 - \theta_{j'kr}^{po}\right) \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{37}$$

$$\left(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right) / \left(D_k^{''po} \times t_{j'kr}^{'''po}\right) \leq N \times \theta_{j'kr}^{po} \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O. \tag{38}$$

In this section, $\tau_k^{po} \in \{0,1\}$ is defined to make equation (30) linear based on equations (13) and (22). Thus, we will have the following: $D_k^{''po} - (\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po}) \geq 0$ and $c_k^{po} \geq 0$. Equations (39) and (40) are thus added as follows:

$$c_k^{po} \leq N \times \left(1 - \tau_k^{po}\right) \quad \forall k \in K,\ p \in P,\ o \in O. \tag{39}$$

$$D_k^{''po} - \left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po} \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po}\right) \leq N \times \tau_k^{po} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{40}$$

$\varepsilon_k^{po} \in \{0,1\}$ is used to make equation (31) linear based on equations (14) and (23). Thus, we will have: $(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po}) - [\varphi_k^{''po} \times D_k^{''po}] \geq 0$ and $d_k^{po} \geq 0$. Equations (41) and (42) are thus added as follows:

$$d_k^{po} \leq N \times \left(1 - \varepsilon_k^{po}\right) \quad \forall k \in K,\ p \in P,\ o \in O. \tag{41}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po}\right) - \left[\varphi_k^{'''po} \times D_k^{''po}\right] \leq N \times \varepsilon_k^{po} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{42}$$

Eventually, $\sigma_k^{po} \in \{0,1\}$ is used to make equation (32) linear based on equations (15) and (24). Thus, we will have the following: $(\sum_{j\in J}\sum_{k\in K}\sum_{r\in R} t_{jkr}^{''po} - \sum_{j'\in J}\sum_{k\in K}\sum_{r\in R} t_{j'kr}^{'''po}) \geq 0$ and $e_k^{po} \geq 0$. Equations (43) and (44) are thus added as follows:

$$e_k^{po} \leq N \times \left(1 - \sigma_k^{po}\right) \quad \forall k \in K,\ p \in P,\ o \in O. \tag{43}$$

$$\left(\sum_{j\in J}\sum_{r\in R} t_{jkr}^{''po} - \sum_{j'\in J}\sum_{r\in R} t_{j'kr}^{'''po}\right) \leq N \times \sigma_k^{po} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{44}$$

The fifth step is creating a multiperiod integer linear planning model of M_3.

$$\min_{\substack{x_{ijr}^{po},x_{jkr}^{''po},x_{ij'r}^{'po},x_{j'kr}^{'''po},b_j^{po},b_{j'}^{po},c_k^{po},\\ d_k^{po},e_k^{po},\theta_{jkr}^{po},\theta_{j'kr}^{po},\tau_k^{po},\varepsilon_k^{po},\sigma_k^{po}}} \sum_{o\in O}\sum_{p\in P}\left(4-\left(\sum_{i\in I}\sum_{j\in J}\sum_{r\in R}\frac{w_j^p\times x_{ijr}^{po}}{D_j^{po}}+\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R}\frac{w_{j'}^{'p}\times x_{ij'r}^{'po}}{D_{j'}^{'po}}\right)\right.$$
$$\left.-\left(\sum_{j\in J}\sum_{k\in K}\sum_{r\in R}\frac{w_k^{''p}\times x_{jkr}^{''po}}{D_k^{''po}}+\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R}\frac{w_k^{'''p}\times x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right)$$

$$\min_{\substack{x_{ijr}^{po},x_{jkr}^{''po},x_{ij'r}^{'po},x_{j'kr}^{'''po},b_j^{po},b_{j'}^{po},c_k^{po},d_k^{po},e_k^{po},\\ \theta_{jkr}^{po},\theta_{j'kr}^{po},\tau_k^{po},\varepsilon_k^{po},\sigma_k^{po}}} \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R}\pi G_{ijr}\times t_{ijr}^{po}\times x_{ijr}^{po}+\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R}\pi G_{ij'r}'\times t_{ij'r}^{'po}\times x_{ij'r}^{'po}\right)$$
$$+\left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R}\pi G_{jkr}''\times t_{jkr}^{''po}\times x_{jkr}^{''po}+\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R}\pi G_{j'kr}''\times t_{j'kr}^{'''po}\times x_{j'kr}^{'''po}\right) \tag{45}$$
$$+\left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R}\delta_k^o\times U^o\times x_{jkr}^{''po}+\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R}\delta_k^o\times U^o\times x_{j'kr}^{'''po}\right)$$

$$\min_{\substack{x_{ijr}^{po},x_{jkr}^{''po},x_{ij'r}^{'po},x_{j'kr}^{'''po},b_j^{po},b_{j'}^{po},c_k^{po},d_k^{po},e_k^{po},\\ \theta_{jkr}^{po},\theta_{j'kr}^{po},\tau_k^{po},\varepsilon_k^{po},\sigma_k^{po}}} \left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R}S_{ijr}^o\times x_{ijr}^{po}\right)+\left(\sum_{o\in O}\sum_{p\in P}\sum_{i\in I}\sum_{j'\in J}\sum_{r\in R}S_{ij'r}^{'o}\times x_{ij'r}^{'po}\right)$$
$$+\left(\sum_{o\in O}\sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R}S_{jkr}^{''o}\times x_{jkr}^{''po}\right)+\left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R}S_{j'kr}^{'''o}\times x_{j'kr}^{'''po}\right)$$
$$+\left(\sum_{o\in O}\sum_{p\in P}\sum_{j'\in J}\sum_{k\in K}\sum_{r\in R}B_{j'k}^{po}\times\left(w_k^{''p}\times\frac{x_{j'kr}^{'''po}}{D_k^{''po}}\right)\right).$$

Subject to:

$$\left(\sum_{j\in J}\sum_{r\in R}x_{ijr}^{po}+\sum_{j'\in J}\sum_{r\in R}x_{ij'r}^{'po}\right)=\frac{\left(Q_{iL}^{po}+2Q_{iH}^{po}+Q_{iU}^{po}\right)}{4}\quad \forall i\in I,\ p\in P,\ o\in O. \tag{46}$$

$$\sum_{i\in I}\sum_{r\in R}x_{ijr}^{po}\le D_j^{po}\quad \forall j\in J,\ p\in P,\ o\in O. \tag{47}$$

$$\sum_{i\in I}\sum_{r\in R}x_{ij'r}^{'po}\le D_{j'}^{'po}\quad \forall j'\in J,\ p\in P,\ o\in O. \tag{48}$$

$$\sum_{i\in I}\sum_{r\in R}x_{ijr}^{po}\ge\left[\varphi_j^{po}D_j^{po}\right]\quad \forall j\in J,\ p\in P,\ o\in O. \tag{49}$$

$$\sum_{i\in I}\sum_{r\in R}x_{ij'r}^{'po}\ge\left[\varphi_{j'}^{'po}D_{j'}^{'po}\right]\quad \forall j'\in J,\ p\in P,\ o\in O. \tag{50}$$

$$\left(\sum_{i\in I}\sum_{r\in R} t_{ijr}^{po} + \sum_{i\in I}\sum_{r\in R} t_{ij'r}^{'po}\right) + \left(\sum_{k\in K}\sum_{r\in R} t_{jkr}^{''po} + \sum_{k\in K}\sum_{r\in R} t_{j'kr}^{'''po}\right) \le T \quad \forall (j, j') \in J,\ p \in P,\ o \in O, \tag{51}$$

$$x_{ijr}^{po}, x_{ij'r}^{'po} \text{ are non} - \text{negative integer variables} \quad \forall i \in I,\ (j, j') \in J,\ r \in R,\ p \in P,\ o \in O, \tag{52}$$

$$\left(\sum_{k\in K}\sum_{r\in R} x_{jkr}^{''po} + \sum_{k\in K}\sum_{r\in R} x_{j'kr}^{''po}\right) = \left(\sum_{i\in I}\sum_{r\in R} x_{ijr}^{po} + \sum_{i\in I}\sum_{r\in R} x_{ij'r}^{''po}\right) \quad \forall (j, j') \in J,\ p \in P,\ o \in O, \tag{53}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{'''po}\right) \le D_k^{''po} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{54}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x_{jkr}^{''po} + \sum_{j'\in J}\sum_{r\in R} x_{j'kr}^{''po}\right) \ge \left[\varphi_k^{''po} D_k^{''po}\right] \quad \forall k \in K,\ p \in P,\ o \in O, \tag{55}$$

$$\sum_{j\in J}\sum_{r\in R} t_{jkr}^{''po} \ge \sum_{j'\in J}\sum_{r\in R} t_{j'kr}^{'''po} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{56}$$

$$x_{jkr}^{''po}, x_{j'kr}^{'''po} \text{ are non} - \text{negative integer variables} \quad \forall (j, j') \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{57}$$

$$\left(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po}\right) \ge \frac{w_k^{''p}}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)} \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{58}$$

$$\left(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po}\right) \ge \frac{w_k^{''p}}{\left(D_k^{''po} \times t_{j'kr}^{'''po}\right)} \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{59}$$

$$b_j^{po}, b_{j'}^{po} \text{ urs} \quad \forall (j, j') \in J,\ p \in P,\ o \in O, \tag{60}$$

$$c_k^{po} \ge 0 \quad \forall k \in K,\ p \in P,\ o \in O, \tag{61}$$

$$d_k^{po} \ge 0 \quad \forall k \in K,\ p \in P,\ o \in O, \tag{62}$$

$$e_k^{po} \ge 0 \quad \forall k \in K,\ p \in P,\ o \in O, \tag{63}$$

$$x_{jkr}^{''po} \le N \times \left(1 - \theta_{jkr}^{po}\right) \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{64}$$

$$\frac{\left(b_j^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right)}{\left(D_k^{''po} \times t_{jkr}^{''po}\right)} \le N \times \theta_{jkr}^{po} \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{65}$$

$$x_{j'kr}^{'''po} \le N \times \left(1 - \theta_{j'kr}^{po}\right) \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{66}$$

$$\frac{\left(b_{j'}^{po} + c_k^{po} - d_k^{po} - e_k^{po} - w_k^{''p}\right)}{\left(D_k^{''po} \times t_{j'kr}^{'''po}\right)} \le N \times \theta_{j'kr}^{po} \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{67}$$

$$c_k^{po} \le N \times \left(1 - \tau_k^{po}\right) \quad \forall k \in K,\ p \in P,\ o \in O, \tag{68}$$

$$D''^{po}_{k} - \left(\sum_{j\in J}\sum_{r\in R} x''^{po}_{jkr} + \sum_{j'\in J}\sum_{r\in R} x'''^{po}_{j'kr}\right) \le N \times \tau^{po}_{k} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{69}$$

$$d^{po}_{k} \le N \times \left(1 - \varepsilon^{po}_{k}\right) \quad \forall k \in K,\ p \in P,\ o \in O, \tag{70}$$

$$\left(\sum_{j\in J}\sum_{r\in R} x'^{po}_{jkr} + \sum_{j'\in J}\sum_{r\in R} x'l^{po}_{j'kr}\right) - \left[\varphi l^{po}_{k} \times D'^{po}_{k}\right] \le N \times \varepsilon^{po}_{k} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{71}$$

$$e^{po}_{k} \le N \times \left(1 - \sigma^{po}_{k}\right) \quad \forall k \in K,\ p \in P,\ o \in O, \tag{72}$$

$$\left(\sum_{j\in J}\sum_{r\in R} t''^{po}_{jkr} - \sum_{j'\in J}\sum_{r\in R} t'''^{po}_{j'kr}\right) \le N \times \sigma^{po}_{k} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{73}$$

$$\theta^{po}_{jkr} \in \{0,1\} \quad \forall j \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{74}$$

$$\theta^{po}_{j'kr} \in \{0,1\} \quad \forall j' \in J,\ k \in K,\ r \in R,\ p \in P,\ o \in O, \tag{75}$$

$$\tau^{po}_{k} \in \{0,1\} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{76}$$

$$\varepsilon^{po}_{k} \in \{0,1\} \quad \forall k \in K,\ p \in P,\ o \in O, \tag{77}$$

$$\sigma^{po}_{k} \in \{0,1\} \quad \forall k \in K,\ p \in P,\ o \in O. \tag{78}$$

The sixth step is solving the model.

F_1, F_2, and F_3 demonstrate the three-objective model of the M_3, respectively. The branch-and-bound approach is then used to solve the single-objective mixed-integer planning model, using either (F_1) as the unmet demand rate, (F_2) as the total environmental damage, or (F_3) as total costs considered. The final value of each objective function will eventually be demonstrated by $F_1^{\min}$, $F_2^{\min}$, and $F_3^{\min}$.

In the seventh step, the M_3 model is rewritten as a single-objective model. Equation (79) [24] is used for this purpose. This equation is a weighted linear summation for converting a multiobjective problem to a single-objective problem. Thus, we have the following equation:

$$\min F = \alpha_1\left(\frac{F_1 - F_1^{\min}}{F_1^{\min}}\right) + \alpha_2\left(\frac{F_2 - F_2^{\min}}{F_2^{\min}}\right) + \alpha_3\left(\frac{F_3 - F_3^{\min}}{F_3^{\min}}\right). \tag{79}$$

Now, the model is solved and tested considering the above objective function and equations (46)-(78) so that α_1, α_2, and α_3 are the weights of decision-making factors relevant to the sustainable goals.

$\alpha_1 + \alpha_2 + \alpha_3 = 1$ and $\alpha_1 > \alpha_2 = \alpha_3$ should also be applied, given that the social sustainability goal was more important than environmental and economic sustainability goals for managers [24].

4.2. Parameter Setting. It is noteworthy that the multiobjective evolutionary algorithm based on decomposition (MOEA/D) [26] was implemented using MATLAB to solve the model. Accordingly, the optimal algorithm implementation condition is a subset with a minimum number of unresponded demands, destructive environmental effects, and costs. The considered assumptions are as follows: the relief operation is carried out with four suppliers and three distributors (one of them is a private distributor and two others are public distributors); four demand points for three periods. The model is examined via the mentioned assumptions, and the parameters of the model are valued as follows in Tables 2-31:

Further, $T = 14400$h, $\pi = 0.4$ and r = 2.

5. System Hardware Specifications for the Calculations

We used a laptop with 8 MB RAM, a 7-core Intel processor, and 64-bit Windows 10 to program and test the proposed method as well as the methods being compared in MATLAB. In addition, there was no specific limit on storage. A 1TB hard drive with approximately 700 GB of free space was utilized. The 2019a version of MATLAB was also used to conduct the tests on the proposed method and the method in comparison.

Table 2: Values of the input parameter $\mathbf{w}_j^p$.

$\mathbf{w}_1^1$	0.02
$\mathbf{w}_1^2$	0.07
$\mathbf{w}_1^3$	0.2
$\mathbf{w}_2^1$	0.1
$\mathbf{w}_2^2$	0.012
$\mathbf{w}_2^3$	0.06

Table 3: Values of the input parameter $\mathbf{w}_j^{'p}$.

$\mathbf{w}_1^{'1}$	0.11
$\mathbf{w}_1^{'2}$	0.27
$\mathbf{w}_1^{'3}$	0.08

Table 4: Values of the input parameter $\mathbf{w}_k^{''p}$.

$\mathbf{w}_1^{''1}$	0.09
$\mathbf{w}_1^{''2}$	0.2
$\mathbf{w}_1^{''3}$	0.21
$\mathbf{w}_2^{''1}$	0.36
$\mathbf{w}_2^{''2}$	0.6
$\mathbf{w}_2^{''3}$	0.11
$\mathbf{w}_3^{''1}$	0.17
$\mathbf{w}_3^{''2}$	0.1
$\mathbf{w}_3^{''3}$	0.13
$\mathbf{w}_4^{''1}$	0.08
$\mathbf{w}_4^{''2}$	0.9
$\mathbf{w}_4^{''3}$	0.26

Table 5: Values of the input parameter $\mathbf{D}_j^{po}$.

$\mathbf{D}_1^{11}$	401679
$\mathbf{D}_1^{21}$	624630
$\mathbf{D}_1^{31}$	994986
$\mathbf{D}_2^{11}$	390624
$\mathbf{D}_2^{21}$	602519
$\mathbf{D}_2^{31}$	1013412
$\mathbf{D}_1^{12}$	20268
$\mathbf{D}_1^{22}$	30678
$\mathbf{D}_1^{32}$	51591
$\mathbf{D}_2^{12}$	18794
$\mathbf{D}_2^{22}$	30374
$\mathbf{D}_2^{32}$	49749
$\mathbf{D}_1^{13}$	4974
$\mathbf{D}_1^{23}$	7738
$\mathbf{D}_1^{33}$	13013
$\mathbf{D}_2^{13}$	4652
$\mathbf{D}_2^{23}$	7600
$\mathbf{D}_2^{33}$	12667

Table 6: Values of the input parameter $\mathbf{D}_j^{'po}$.

$\mathbf{D}_1^{'11}$	412735
$\mathbf{D}_1^{'21}$	630158
$\mathbf{D}_1^{'31}$	1050264
$\mathbf{D}_1^{'12}$	20821
$\mathbf{D}_1^{'22}$	33442
$\mathbf{D}_1^{'32}$	54355
$\mathbf{D}_1^{'13}$	5389
$\mathbf{D}_1^{'23}$	8015
$\mathbf{D}_1^{'33}$	12782

Table 7: Values of the input parameter $\mathbf{D}_k^{''po}$.

$\mathbf{D}_1^{''11}$	109479
$\mathbf{D}_1^{''21}$	164218
$\mathbf{D}_1^{''31}$	273697
$\mathbf{D}_2^{''11}$	88289
$\mathbf{D}_2^{''21}$	132434
$\mathbf{D}_2^{''31}$	220724
$\mathbf{D}_3^{''11}$	98884
$\mathbf{D}_3^{''21}$	148326
$\mathbf{D}_3^{''31}$	247211
$\mathbf{D}_4^{''11}$	56505
$\mathbf{D}_4^{''21}$	84758
$\mathbf{D}_4^{''31}$	141263
$\mathbf{D}_1^{''12}$	4414
$\mathbf{D}_1^{''22}$	6622
$\mathbf{D}_1^{''32}$	11036
$\mathbf{D}_2^{''12}$	4767
$\mathbf{D}_2^{''22}$	7151
$\mathbf{D}_2^{''32}$	11919
$\mathbf{D}_3^{''12}$	3884
$\mathbf{D}_3^{''22}$	5827
$\mathbf{D}_3^{''32}$	9711
$\mathbf{D}_4^{''12}$	4591
$\mathbf{D}_4^{''22}$	6887
$\mathbf{D}_4^{''32}$	11477
$\mathbf{D}_1^{''13}$	1191
$\mathbf{D}_1^{''23}$	1787
$\mathbf{D}_1^{''33}$	2979
$\mathbf{D}_2^{''13}$	1059
$\mathbf{D}_2^{''23}$	1589
$\mathbf{D}_2^{''33}$	2648
$\mathbf{D}_3^{''13}$	926
$\mathbf{D}_3^{''23}$	1390
$\mathbf{D}_3^{''33}$	2317
$\mathbf{D}_4^{''13}$	1235
$\mathbf{D}_4^{''23}$	1854
$\mathbf{D}_4^{''33}$	3090

Table 32 illustrates the control parameters used in MOEA/D to solve the proposed chain problem. The population size parameter indicates the number of solutions in the MOEA/D search space, which has been considered 20 through a trial and error test. As mentioned, the function of heuristic optimization methods is derived from generating multiple solutions to a problem in the optimization search space, and then, discovering and brainstorming the solutions to extract the proper solution, that is, the best solution as the response to the

Table 8: Values of the input parameter $\mathbf{G_{ijr}}$.

$\mathbf{G}_{111}$	0.295
$\mathbf{G}_{211}$	0.149
$\mathbf{G}_{311}$	0.138
$\mathbf{G}_{121}$	0.252
$\mathbf{G}_{221}$	0.068
$\mathbf{G}_{321}$	0.189
$\mathbf{G}_{112}$	0.314
$\mathbf{G}_{212}$	0.189
$\mathbf{G}_{312}$	0.368
$\mathbf{G}_{122}$	0.347
$\mathbf{G}_{222}$	0.242
$\mathbf{G}_{322}$	0.247

Table 9: Values of the input parameter $\mathbf{G'_{ij'r}}$.

$\mathbf{G}'_{111}$	0.173
$\mathbf{G}'_{211}$	0.012
$\mathbf{G}'_{311}$	0.141
$\mathbf{G}'_{112}$	0.255
$\mathbf{G}'_{212}$	0.396
$\mathbf{G}'_{312}$	0.187

Table 10: Values of the input parameter $\mathbf{G''_{jkr}}$.

$\mathbf{G}''_{111}$	0.311
$\mathbf{G}''_{121}$	0.049
$\mathbf{G}''_{131}$	0.225
$\mathbf{G}''_{131}$	0.301
$\mathbf{G}''_{211}$	0.165
$\mathbf{G}''_{221}$	0.103
$\mathbf{G}''_{231}$	0.124
$\mathbf{G}''_{241}$	0.146
$\mathbf{G}''_{112}$	0.411
$\mathbf{G}''_{122}$	0.270
$\mathbf{G}''_{131}$	0.375
$\mathbf{G}''_{131}$	0.306
$\mathbf{G}''_{212}$	0.184
$\mathbf{G}''_{222}$	0.372
$\mathbf{G}''_{232}$	0.148
$\mathbf{G}''_{242}$	0.279

Table 11: Values of the input parameter $\mathbf{G'''_{j'kr}}$.

$\mathbf{G}'''_{111}$	0.561
$\mathbf{G}'''_{121}$	0.203
$\mathbf{G}'''_{131}$	0.227
$\mathbf{G}'''_{141}$	0.312
$\mathbf{G}'''_{112}$	0.321
$\mathbf{G}'''_{122}$	0.299
$\mathbf{G}'''_{132}$	0.286
$\mathbf{G}'''_{142}$	0.239

Table 12: Values of the input parameter $\mathbf{t^{po}_{ijr}}$.

$\mathbf{t}^{11}_{111}$	19.32
$\mathbf{t}^{11}_{211}$	33.12
$\mathbf{t}^{11}_{311}$	15.18
$\mathbf{t}^{21}_{111}$	12.6
$\mathbf{t}^{21}_{211}$	19.8
$\mathbf{t}^{21}_{311}$	14.4
$\mathbf{t}^{31}_{111}$	31.2
$\mathbf{t}^{31}_{211}$	38.4
$\mathbf{t}^{31}_{311}$	52.8
$\mathbf{t}^{12}_{111}$	16.5
$\mathbf{t}^{12}_{211}$	22.5
$\mathbf{t}^{12}_{311}$	24
$\mathbf{t}^{22}_{111}$	9.9
$\mathbf{t}^{22}_{211}$	13.5
$\mathbf{t}^{22}_{311}$	16.2
$\mathbf{t}^{32}_{111}$	23.1
$\mathbf{t}^{32}_{211}$	31.5
$\mathbf{t}^{32}_{311}$	56.7
$\mathbf{t}^{13}_{111}$	26.4
$\mathbf{t}^{13}_{211}$	64.8
$\mathbf{t}^{13}_{311}$	38.4
$\mathbf{t}^{23}_{111}$	29.7
$\mathbf{t}^{23}_{211}$	43.2
$\mathbf{t}^{23}_{311}$	72.9
$\mathbf{t}^{33}_{111}$	36.3
$\mathbf{t}^{33}_{211}$	89.1
$\mathbf{t}^{33}_{311}$	52.8
$\mathbf{t}^{11}_{121}$	30.36
$\mathbf{t}^{11}_{221}$	22.08
$\mathbf{t}^{11}_{321}$	17.9
$\mathbf{t}^{21}_{121}$	9.9
$\mathbf{t}^{21}_{221}$	21.6
$\mathbf{t}^{21}_{321}$	11.7
$\mathbf{t}^{31}_{121}$	33.6
$\mathbf{t}^{31}_{221}$	26.4
$\mathbf{t}^{31}_{321}$	57.6
$\mathbf{t}^{12}_{121}$	40.5
$\mathbf{t}^{12}_{221}$	19.5
$\mathbf{t}^{12}_{321}$	27
$\mathbf{t}^{22}_{121}$	11.7
$\mathbf{t}^{22}_{221}$	14.4
$\mathbf{t}^{22}_{321}$	24.3
$\mathbf{t}^{32}_{121}$	27.3
$\mathbf{t}^{32}_{221}$	33.6
$\mathbf{t}^{32}_{321}$	37.8
$\mathbf{t}^{13}_{121}$	31.2
$\mathbf{t}^{13}_{221}$	36
$\mathbf{t}^{13}_{321}$	43.2
$\mathbf{t}^{23}_{121}$	35.1
$\mathbf{t}^{23}_{221}$	48.6
$\mathbf{t}^{23}_{321}$	40.5
$\mathbf{t}^{33}_{121}$	42.9
$\mathbf{t}^{33}_{221}$	49.5
$\mathbf{t}^{33}_{321}$	59.4
$\mathbf{t}^{11}_{112}$	31.02
$\mathbf{t}^{11}_{212}$	42.30
$\mathbf{t}^{11}_{312}$	39.48
$\mathbf{t}^{21}_{112}$	16.5
$\mathbf{t}^{21}_{212}$	22.5
$\mathbf{t}^{21}_{312}$	24
$\mathbf{t}^{31}_{112}$	52.8
$\mathbf{t}^{31}_{212}$	67.2

Table 12: Continued.

$\mathbf{t}^{31}_{312}$	76.8
$\mathbf{t}^{12}_{112}$	50.7
$\mathbf{t}^{12}_{212}$	42.9
$\mathbf{t}^{12}_{312}$	109.2
$\mathbf{t}^{22}_{112}$	20.4
$\mathbf{t}^{22}_{212}$	14.4
$\mathbf{t}^{22}_{312}$	26.4
$\mathbf{t}^{32}_{112}$	39.6
$\mathbf{t}^{32}_{212}$	56.1
$\mathbf{t}^{32}_{312}$	59.4
$\mathbf{t}^{13}_{112}$	43.2
$\mathbf{t}^{13}_{212}$	57.6
$\mathbf{t}^{13}_{312}$	72
$\mathbf{t}^{23}_{112}$	43.2
$\mathbf{t}^{23}_{212}$	61.2
$\mathbf{t}^{23}_{312}$	57.6
$\mathbf{t}^{33}_{112}$	91.2
$\mathbf{t}^{33}_{212}$	114
$\mathbf{t}^{33}_{312}$	79.8
$\mathbf{t}^{11}_{122}$	47.94
$\mathbf{t}^{11}_{222}$	45.12
$\mathbf{t}^{11}_{322}$	76.14
$\mathbf{t}^{21}_{122}$	25.5
$\mathbf{t}^{21}_{222}$	21
$\mathbf{t}^{21}_{322}$	40.5
$\mathbf{t}^{31}_{122}$	81.6
$\mathbf{t}^{31}_{222}$	72
$\mathbf{t}^{31}_{322}$	129.6
$\mathbf{t}^{12}_{122}$	50.6
$\mathbf{t}^{12}_{222}$	54.6
$\mathbf{t}^{12}_{322}$	81.8
$\mathbf{t}^{22}_{122}$	16.8
$\mathbf{t}^{22}_{222}$	21.6
$\mathbf{t}^{22}_{322}$	16.8
$\mathbf{t}^{32}_{122}$	46.2
$\mathbf{t}^{32}_{222}$	59.1
$\mathbf{t}^{32}_{322}$	72.6
$\mathbf{t}^{13}_{122}$	50.4
$\mathbf{t}^{13}_{222}$	61.2
$\mathbf{t}^{13}_{322}$	75.6
$\mathbf{t}^{23}_{122}$	50.4
$\mathbf{t}^{23}_{222}$	72
$\mathbf{t}^{23}_{322}$	75.6
$\mathbf{t}^{33}_{122}$	68.4
$\mathbf{t}^{33}_{222}$	96.9
$\mathbf{t}^{33}_{322}$	119.7

problem. The reservoir parameter stores the dominant solutions throughout each iteration. Given that there are three objectives when faced with multiple objectives in heuristic optimization algorithms, we require a reservoir to store the most optimal solution in the form of the Pareto archive. The number of objective parameter depicts the number of objectives in the optimization algorithm: the first objective is the minimization of unresponded demands, the second objective is the minimization of destructive environmental effects, and the third objective is the costs of the supply chain. Also, maximum iterations show the limit of the algorithm implementation to obtain convergence, which is also the termination condition of the algorithm. The algorithm continues until it achieves convergence or maximum iterations.

Table 13: Values of the input parameter $\mathbf{t}'^{po}_{ij'r}$.

$\mathbf{t}'^{11}_{111}$	38.4
$\mathbf{t}'^{11}_{211}$	32.4
$\mathbf{t}'^{11}_{311}$	49.2
$\mathbf{t}'^{21}_{111}$	8.4
$\mathbf{t}'^{21}_{211}$	9.3
$\mathbf{t}'^{11}_{311}$	12.3
$\mathbf{t}'^{31}_{111}$	40.02
$\mathbf{t}'^{31}_{211}$	41.4
$\mathbf{t}'^{31}_{311}$	56.58
$\mathbf{t}'^{12}_{111}$	27.9
$\mathbf{t}'^{12}_{211}$	27.9
$\mathbf{t}'^{12}_{311}$	34.2
$\mathbf{t}'^{22}_{111}$	46.5
$\mathbf{t}'^{22}_{211}$	46.5
$\mathbf{t}'^{22}_{311}$	57
$\mathbf{t}'^{32}_{111}$	52.08
$\mathbf{t}'^{32}_{211}$	52.08
$\mathbf{t}'^{32}_{311}$	63.84
$\mathbf{t}'^{13}_{111}$	69.3
$\mathbf{t}'^{13}_{211}$	65.1
$\mathbf{t}'^{13}_{311}$	75.6
$\mathbf{t}'^{23}_{111}$	28.8
$\mathbf{t}'^{23}_{211}$	27.36
$\mathbf{t}'^{23}_{311}$	15.84
$\mathbf{t}'^{33}_{111}$	50.4
$\mathbf{t}'^{33}_{211}$	41.58
$\mathbf{t}'^{33}_{311}$	34.02
$\mathbf{t}'^{11}_{112}$	76.8
$\mathbf{t}'^{11}_{212}$	64.8
$\mathbf{t}'^{11}_{312}$	98.4
$\mathbf{t}'^{11}_{112}$	30.6
$\mathbf{t}'^{21}_{212}$	24.3
$\mathbf{t}'^{21}_{312}$	35.1
$\mathbf{t}'^{31}_{112}$	95.88
$\mathbf{t}'^{31}_{212}$	76.14
$\mathbf{t}'^{31}_{312}$	109.98
$\mathbf{t}'^{12}_{112}$	60
$\mathbf{t}'^{12}_{212}$	57
$\mathbf{t}'^{12}_{312}$	33
$\mathbf{t}'^{22}_{112}$	69.3
$\mathbf{t}'^{22}_{212}$	65.1
$\mathbf{t}'^{22}_{312}$	75.6
$\mathbf{t}'^{32}_{112}$	93.06
$\mathbf{t}'^{32}_{212}$	87.42
$\mathbf{t}'^{32}_{312}$	101.52
$\mathbf{t}'^{13}_{112}$	132
$\mathbf{t}'^{13}_{212}$	105.3
$\mathbf{t}'^{13}_{312}$	152.1
$\mathbf{t}'^{23}_{112}$	57.12
$\mathbf{t}'^{23}_{212}$	45.36
$\mathbf{t}'^{23}_{312}$	65.52
$\mathbf{t}'^{33}_{112}$	84.24
$\mathbf{t}'^{33}_{212}$	113.4
$\mathbf{t}'^{33}_{312}$	126.36

Table 14: Values of the input parameter $\mathbf{t}_{\mathbf{jkr}}^{\prime\prime\mathbf{po}}$.

$\mathbf{t}_{111}^{\prime\prime 11}$	9.75
$\mathbf{t}_{121}^{\prime\prime 11}$	12.48
$\mathbf{t}_{131}^{\prime\prime 11}$	8.19
$\mathbf{t}_{141}^{\prime\prime 11}$	8.58
$\mathbf{t}_{111}^{\prime\prime 21}$	40.32
$\mathbf{t}_{121}^{\prime\prime 21}$	32.76
$\mathbf{t}_{131}^{\prime\prime 21}$	27.72
$\mathbf{t}_{141}^{\prime\prime 21}$	25.2
$\mathbf{t}_{111}^{\prime\prime 31}$	20.25
$\mathbf{t}_{121}^{\prime\prime 31}$	16.2
$\mathbf{t}_{131}^{\prime\prime 31}$	25.92
$\mathbf{t}_{141}^{\prime\prime 31}$	18.63
$\mathbf{t}_{111}^{\prime\prime 12}$	13.5
$\mathbf{t}_{121}^{\prime\prime 12}$	17.28
$\mathbf{t}_{131}^{\prime\prime 12}$	11.34
$\mathbf{t}_{141}^{\prime\prime 12}$	11.88
$\mathbf{t}_{111}^{\prime\prime 22}$	26.1
$\mathbf{t}_{121}^{\prime\prime 22}$	22.62
$\mathbf{t}_{131}^{\prime\prime 22}$	20.88
$\mathbf{t}_{141}^{\prime\prime 22}$	17.4
$\mathbf{t}_{111}^{\prime\prime 32}$	15.75
$\mathbf{t}_{121}^{\prime\prime 32}$	12.6
$\mathbf{t}_{131}^{\prime\prime 32}$	20.16
$\mathbf{t}_{141}^{\prime\prime 32}$	14.49
$\mathbf{t}_{111}^{\prime\prime 13}$	21
$\mathbf{t}_{121}^{\prime\prime 13}$	23.52
$\mathbf{t}_{131}^{\prime\prime 13}$	17.64
$\mathbf{t}_{141}^{\prime\prime 13}$	21.84
$\mathbf{t}_{111}^{\prime\prime 23}$	35.4
$\mathbf{t}_{121}^{\prime\prime 23}$	30.42
$\mathbf{t}_{131}^{\prime\prime 23}$	28.08
$\mathbf{t}_{141}^{\prime\prime 23}$	23.4
$\mathbf{t}_{111}^{\prime\prime 33}$	13.5
$\mathbf{t}_{121}^{\prime\prime 33}$	10.8
$\mathbf{t}_{131}^{\prime\prime 33}$	17.28
$\mathbf{t}_{141}^{\prime\prime 33}$	12.42
$\mathbf{t}_{211}^{\prime\prime 11}$	8.2
$\mathbf{t}_{221}^{\prime\prime 11}$	10.54
$\mathbf{t}_{231}^{\prime\prime 11}$	21.3
$\mathbf{t}_{241}^{\prime\prime 11}$	9.45
$\mathbf{t}_{211}^{\prime\prime 21}$	42.14
$\mathbf{t}_{221}^{\prime\prime 21}$	31.21
$\mathbf{t}_{231}^{\prime\prime 21}$	21.54
$\mathbf{t}_{241}^{\prime\prime 21}$	22.36
$\mathbf{t}_{211}^{\prime\prime 31}$	15
$\mathbf{t}_{221}^{\prime\prime 31}$	14.5
$\mathbf{t}_{231}^{\prime\prime 31}$	22.1
$\mathbf{t}_{241}^{\prime\prime 31}$	17.6
$\mathbf{t}_{211}^{\prime\prime 12}$	12.1
$\mathbf{t}_{221}^{\prime\prime 12}$	11.32
$\mathbf{t}_{231}^{\prime\prime 12}$	9.23
$\mathbf{t}_{241}^{\prime\prime 12}$	10.6
$\mathbf{t}_{211}^{\prime\prime 22}$	14.5
$\mathbf{t}_{221}^{\prime\prime 22}$	12.5
$\mathbf{t}_{231}^{\prime\prime 22}$	19.54

Table 14: Continued.

$\mathbf{t}_{241}^{\prime\prime 22}$	18.05
$\mathbf{t}_{211}^{\prime\prime 32}$	13.87
$\mathbf{t}_{221}^{\prime\prime 32}$	14.41
$\mathbf{t}_{231}^{\prime\prime 32}$	16.97
$\mathbf{t}_{241}^{\prime\prime 32}$	13.61
$\mathbf{t}_{211}^{\prime\prime 13}$	18.5
$\mathbf{t}_{221}^{\prime\prime 13}$	24.5
$\mathbf{t}_{231}^{\prime\prime 13}$	15.05
$\mathbf{t}_{241}^{\prime\prime 13}$	19.02
$\mathbf{t}_{211}^{\prime\prime 23}$	5.48
$\mathbf{t}_{221}^{\prime\prime 23}$	7.54
$\mathbf{t}_{231}^{\prime\prime 23}$	19.54
$\mathbf{t}_{241}^{\prime\prime 23}$	12.5
$\mathbf{t}_{211}^{\prime\prime 33}$	10.4
$\mathbf{t}_{221}^{\prime\prime 33}$	8.5
$\mathbf{t}_{231}^{\prime\prime 33}$	21.2
$\mathbf{t}_{241}^{\prime\prime 33}$	10.8
$\mathbf{t}_{112}^{\prime\prime 11}$	20.91
$\mathbf{t}_{122}^{\prime\prime 11}$	11.73
$\mathbf{t}_{132}^{\prime\prime 11}$	11.5
$\mathbf{t}_{142}^{\prime\prime 11}$	6.63
$\mathbf{t}_{112}^{\prime\prime 21}$	35.1
$\mathbf{t}_{122}^{\prime\prime 21}$	60.84
$\mathbf{t}_{132}^{\prime\prime 21}$	54.16
$\mathbf{t}_{142}^{\prime\prime 21}$	46.64
$\mathbf{t}_{112}^{\prime\prime 31}$	27.72
$\mathbf{t}_{122}^{\prime\prime 31}$	21.78
$\mathbf{t}_{132}^{\prime\prime 31}$	29.7
$\mathbf{t}_{142}^{\prime\prime 31}$	19.8
$\mathbf{t}_{112}^{\prime\prime 12}$	72.96
$\mathbf{t}_{122}^{\prime\prime 12}$	40.32
$\mathbf{t}_{132}^{\prime\prime 12}$	46.08
$\mathbf{t}_{142}^{\prime\prime 12}$	32.64
$\mathbf{t}_{112}^{\prime\prime 22}$	44.1
$\mathbf{t}_{122}^{\prime\prime 22}$	35.28
$\mathbf{t}_{132}^{\prime\prime 22}$	29.4
$\mathbf{t}_{142}^{\prime\prime 22}$	35.28
$\mathbf{t}_{112}^{\prime\prime 32}$	41.16
$\mathbf{t}_{122}^{\prime\prime 32}$	32.34
$\mathbf{t}_{132}^{\prime\prime 32}$	44.1
$\mathbf{t}_{142}^{\prime\prime 32}$	29.4
$\mathbf{t}_{112}^{\prime\prime 13}$	22.08
$\mathbf{t}_{122}^{\prime\prime 13}$	25.92
$\mathbf{t}_{132}^{\prime\prime 13}$	23.04
$\mathbf{t}_{142}^{\prime\prime 13}$	18.24
$\mathbf{t}_{112}^{\prime\prime 23}$	79.2
$\mathbf{t}_{122}^{\prime\prime 23}$	63.36
$\mathbf{t}_{132}^{\prime\prime 23}$	20.44
$\mathbf{t}_{142}^{\prime\prime 23}$	36.45
$\mathbf{t}_{112}^{\prime\prime 33}$	43.68
$\mathbf{t}_{122}^{\prime\prime 33}$	34.32
$\mathbf{t}_{132}^{\prime\prime 33}$	46.8
$\mathbf{t}_{142}^{\prime\prime 33}$	31.2
$\mathbf{t}_{212}^{\prime\prime 11}$	18.54
$\mathbf{t}_{222}^{\prime\prime 11}$	17.12

Table 14: Continued.

$\mathbf{t}_{232}^{\prime\prime 11}$	10.52
$\mathbf{t}_{242}^{\prime\prime 11}$	15.5
$\mathbf{t}_{212}^{\prime\prime 21}$	15.47
$\mathbf{t}_{222}^{\prime\prime 21}$	10.05
$\mathbf{t}_{232}^{\prime\prime 21}$	15.45
$\mathbf{t}_{242}^{\prime\prime 21}$	25.25
$\mathbf{t}_{212}^{\prime\prime 31}$	25.14
$\mathbf{t}_{222}^{\prime\prime 31}$	22.1
$\mathbf{t}_{232}^{\prime\prime 31}$	28.4
$\mathbf{t}_{242}^{\prime\prime 31}$	11.5
$\mathbf{t}_{212}^{\prime\prime 12}$	12.55
$\mathbf{t}_{222}^{\prime\prime 12}$	25.25
$\mathbf{t}_{232}^{\prime\prime 12}$	15.26
$\mathbf{t}_{242}^{\prime\prime 12}$	29.45
$\mathbf{t}_{212}^{\prime\prime 22}$	21.45
$\mathbf{t}_{222}^{\prime\prime 22}$	29.5
$\mathbf{t}_{232}^{\prime\prime 22}$	21.35
$\mathbf{t}_{242}^{\prime\prime 22}$	30.48
$\mathbf{t}_{212}^{\prime\prime 32}$	28.45
$\mathbf{t}_{222}^{\prime\prime 32}$	27.54
$\mathbf{t}_{232}^{\prime\prime 32}$	31.21
$\mathbf{t}_{242}^{\prime\prime 32}$	26.44
$\mathbf{t}_{212}^{\prime\prime 13}$	24.21
$\mathbf{t}_{222}^{\prime\prime 13}$	23.87
$\mathbf{t}_{232}^{\prime\prime 13}$	19.21
$\mathbf{t}_{242}^{\prime\prime 13}$	16.87
$\mathbf{t}_{212}^{\prime\prime 23}$	21.15
$\mathbf{t}_{222}^{\prime\prime 23}$	12.5
$\mathbf{t}_{232}^{\prime\prime 23}$	15.45
$\mathbf{t}_{242}^{\prime\prime 23}$	26.44
$\mathbf{t}_{212}^{\prime\prime 33}$	12.57
$\mathbf{t}_{222}^{\prime\prime 33}$	10.54
$\mathbf{t}_{232}^{\prime\prime 33}$	15.84
$\mathbf{t}_{242}^{\prime\prime 33}$	22.25

Table 15: Values of the input parameter $\mathbf{t}_{\mathbf{j}'\mathbf{kr}}^{\prime\prime\prime \mathbf{po}}$.

$\mathbf{t}_{111}^{\prime\prime\prime 11}$	17
$\mathbf{t}_{121}^{\prime\prime\prime 11}$	9
$\mathbf{t}_{131}^{\prime\prime\prime 11}$	9
$\mathbf{t}_{141}^{\prime\prime\prime 11}$	5
$\mathbf{t}_{111}^{\prime\prime\prime 21}$	44
$\mathbf{t}_{121}^{\prime\prime\prime 21}$	56
$\mathbf{t}_{131}^{\prime\prime\prime 21}$	62
$\mathbf{t}_{141}^{\prime\prime\prime 21}$	38
$\mathbf{t}_{111}^{\prime\prime\prime 31}$	33
$\mathbf{t}_{121}^{\prime\prime\prime 31}$	30.36
$\mathbf{t}_{131}^{\prime\prime\prime 31}$	42
$\mathbf{t}_{141}^{\prime\prime\prime 31}$	26
$\mathbf{t}_{111}^{\prime\prime\prime 12}$	6.6
$\mathbf{t}_{121}^{\prime\prime\prime 12}$	9.6
$\mathbf{t}_{131}^{\prime\prime\prime 12}$	6.3
$\mathbf{t}_{141}^{\prime\prime\prime 12}$	7.5
$\mathbf{t}_{111}^{\prime\prime\prime 22}$	11
$\mathbf{t}_{121}^{\prime\prime\prime 22}$	15.12

Table 15: Continued.

$\mathbf{t}_{131}^{\prime\prime\prime 22}$	16
$\mathbf{t}_{141}^{\prime\prime\prime 22}$	10.26
$\mathbf{t}_{111}^{\prime\prime\prime 32}$	33
$\mathbf{t}_{121}^{\prime\prime\prime 32}$	33
$\mathbf{t}_{131}^{\prime\prime\prime 32}$	39
$\mathbf{t}_{141}^{\prime\prime\prime 32}$	26
$\mathbf{t}_{111}^{\prime\prime\prime 13}$	35
$\mathbf{t}_{121}^{\prime\prime\prime 13}$	20.7
$\mathbf{t}_{131}^{\prime\prime\prime 13}$	21.6
$\mathbf{t}_{141}^{\prime\prime\prime 13}$	12.6
$\mathbf{t}_{111}^{\prime\prime\prime 23}$	14
$\mathbf{t}_{121}^{\prime\prime\prime 23}$	18
$\mathbf{t}_{131}^{\prime\prime\prime 23}$	20
$\mathbf{t}_{141}^{\prime\prime\prime 23}$	12
$\mathbf{t}_{111}^{\prime\prime\prime 33}$	23
$\mathbf{t}_{121}^{\prime\prime\prime 33}$	25
$\mathbf{t}_{131}^{\prime\prime\prime 33}$	32
$\mathbf{t}_{141}^{\prime\prime\prime 33}$	20
$\mathbf{t}_{112}^{\prime\prime\prime 11}$	53
$\mathbf{t}_{122}^{\prime\prime\prime 11}$	28
$\mathbf{t}_{132}^{\prime\prime\prime 11}$	34
$\mathbf{t}_{142}^{\prime\prime\prime 11}$	20
$\mathbf{t}_{112}^{\prime\prime\prime 21}$	30
$\mathbf{t}_{122}^{\prime\prime\prime 21}$	38
$\mathbf{t}_{132}^{\prime\prime\prime 21}$	42
$\mathbf{t}_{142}^{\prime\prime\prime 21}$	26
$\mathbf{t}_{112}^{\prime\prime\prime 31}$	50.16
$\mathbf{t}_{122}^{\prime\prime\prime 31}$	63
$\mathbf{t}_{132}^{\prime\prime\prime 31}$	70
$\mathbf{t}_{142}^{\prime\prime\prime 31}$	73
$\mathbf{t}_{112}^{\prime\prime\prime 12}$	18
$\mathbf{t}_{122}^{\prime\prime\prime 12}$	26
$\mathbf{t}_{132}^{\prime\prime\prime 12}$	17
$\mathbf{t}_{142}^{\prime\prime\prime 12}$	21
$\mathbf{t}_{112}^{\prime\prime\prime 22}$	27.72
$\mathbf{t}_{122}^{\prime\prime\prime 22}$	35
$\mathbf{t}_{132}^{\prime\prime\prime 22}$	39
$\mathbf{t}_{142}^{\prime\prime\prime 22}$	23
$\mathbf{t}_{112}^{\prime\prime\prime 32}$	60
$\mathbf{t}_{122}^{\prime\prime\prime 32}$	83
$\mathbf{t}_{132}^{\prime\prime\prime 32}$	86
$\mathbf{t}_{142}^{\prime\prime\prime 32}$	57
$\mathbf{t}_{112}^{\prime\prime\prime 13}$	84
$\mathbf{t}_{122}^{\prime\prime\prime 13}$	49
$\mathbf{t}_{132}^{\prime\prime\prime 13}$	51
$\mathbf{t}_{142}^{\prime\prime\prime 13}$	30
$\mathbf{t}_{112}^{\prime\prime\prime 23}$	58
$\mathbf{t}_{122}^{\prime\prime\prime 23}$	73
$\mathbf{t}_{132}^{\prime\prime\prime 23}$	81
$\mathbf{t}_{142}^{\prime\prime\prime 23}$	50
$\mathbf{t}_{112}^{\prime\prime\prime 33}$	47
$\mathbf{t}_{122}^{\prime\prime\prime 33}$	55
$\mathbf{t}_{132}^{\prime\prime\prime 33}$	57
$\mathbf{t}_{142}^{\prime\prime\prime 33}$	37

Table 16: Values of the input parameter δ_k^o.

δ_1^1	0.306
δ_2^1	0.583
δ_3^1	0.253
δ_4^1	0.324
δ_1^2	0.0871
δ_2^2	0.0554
δ_3^2	0.152
δ_4^2	0.234
δ_1^3	0.345
δ_2^3	0.144
δ_3^3	0.1
δ_4^3	0.412

Table 17: Values of the input parameter $\mathbf{U^o}$.

$\mathbf{U}^1$	0.42
$\mathbf{U}^2$	0.25
$\mathbf{U}^3$	0.36

Table 18: Values of the input parameter $\mathbf{S_{ijr}^o}$.

$\mathbf{S}_{111}^1$	200000
$\mathbf{S}_{211}^1$	180000
$\mathbf{S}_{311}^1$	200000
$\mathbf{S}_{111}^2$	140000
$\mathbf{S}_{211}^2$	150000
$\mathbf{S}_{311}^2$	140000
$\mathbf{S}_{111}^3$	1000000
$\mathbf{S}_{211}^3$	1100000
$\mathbf{S}_{311}^3$	1200000
$\mathbf{S}_{121}^1$	200000
$\mathbf{S}_{221}^1$	180000
$\mathbf{S}_{321}^1$	200000
$\mathbf{S}_{121}^2$	140000
$\mathbf{S}_{221}^2$	150000
$\mathbf{S}_{321}^2$	120000
$\mathbf{S}_{121}^3$	1000000
$\mathbf{S}_{221}^3$	2200000
$\mathbf{S}_{321}^3$	2000000
$\mathbf{S}_{112}^1$	80000
$\mathbf{S}_{212}^1$	70000
$\mathbf{S}_{312}^1$	80000
$\mathbf{S}_{112}^2$	40000
$\mathbf{S}_{212}^2$	30000
$\mathbf{S}_{312}^2$	40000
$\mathbf{S}_{112}^3$	700000
$\mathbf{S}_{212}^3$	800000
$\mathbf{S}_{312}^3$	700000
$\mathbf{S}_{122}^1$	80000
$\mathbf{S}_{222}^1$	70000
$\mathbf{S}_{322}^1$	80000
$\mathbf{S}_{122}^2$	40000
$\mathbf{S}_{222}^2$	30000
$\mathbf{S}_{322}^2$	40000
$\mathbf{S}_{122}^3$	700000
$\mathbf{S}_{222}^3$	800000
$\mathbf{S}_{322}^3$	700000

Table 19: Values of the input parameter $\mathbf{S_{ij'r}^{\prime o}}$.

$\mathbf{S}_{111}^{\prime 1}$	250000
$\mathbf{S}_{211}^{\prime 1}$	200000
$\mathbf{S}_{311}^{\prime 1}$	250000
$\mathbf{S}_{111}^{\prime 2}$	150000
$\mathbf{S}_{211}^{\prime 2}$	140000
$\mathbf{S}_{311}^{\prime 2}$	150000
$\mathbf{S}_{111}^{\prime 3}$	2000000
$\mathbf{S}_{211}^{\prime 3}$	15000000
$\mathbf{S}_{311}^{\prime 3}$	2000000
$\mathbf{S}_{112}^{\prime 1}$	70000
$\mathbf{S}_{212}^{\prime 1}$	60000
$\mathbf{S}_{312}^{\prime 1}$	70000
$\mathbf{S}_{112}^{\prime 2}$	40000
$\mathbf{S}_{212}^{\prime 2}$	30000
$\mathbf{S}_{312}^{\prime 2}$	40000
$\mathbf{S}_{112}^{\prime 3}$	800000
$\mathbf{S}_{212}^{\prime 3}$	700000
$\mathbf{S}_{312}^{\prime 3}$	800000

Table 20: Values of the input parameter $\mathbf{S_{jkr}^{\prime\prime o}}$.

$\mathbf{S}_{111}^{\prime\prime 1}$	30000
$\mathbf{S}_{112}^{\prime\prime 1}$	20000
$\mathbf{S}_{211}^{\prime\prime 1}$	40000
$\mathbf{S}_{212}^{\prime\prime 1}$	40000
$\mathbf{S}_{111}^{\prime\prime 2}$	25000
$\mathbf{S}_{112}^{\prime\prime 2}$	17000
$\mathbf{S}_{211}^{\prime\prime 2}$	20000
$\mathbf{S}_{212}^{\prime\prime 2}$	15000
$\mathbf{S}_{111}^{\prime\prime 3}$	120000
$\mathbf{S}_{112}^{\prime\prime 3}$	80000
$\mathbf{S}_{211}^{\prime\prime 3}$	140000
$\mathbf{S}_{212}^{\prime\prime 3}$	80000
$\mathbf{S}_{121}^{\prime\prime 1}$	30000
$\mathbf{S}_{122}^{\prime\prime 1}$	20000
$\mathbf{S}_{221}^{\prime\prime 1}$	40000
$\mathbf{S}_{222}^{\prime\prime 1}$	40000
$\mathbf{S}_{121}^{\prime\prime 2}$	25000
$\mathbf{S}_{122}^{\prime\prime 2}$	17000
$\mathbf{S}_{221}^{\prime\prime 2}$	20000
$\mathbf{S}_{222}^{\prime\prime 2}$	15000
$\mathbf{S}_{121}^{\prime\prime 3}$	120000
$\mathbf{S}_{122}^{\prime\prime 3}$	100000
$\mathbf{S}_{221}^{\prime\prime 3}$	140000
$\mathbf{S}_{222}^{\prime\prime 3}$	80000
$\mathbf{S}_{131}^{\prime\prime 1}$	30000
$\mathbf{S}_{132}^{\prime\prime 1}$	20000
$\mathbf{S}_{231}^{\prime\prime 1}$	40000
$\mathbf{S}_{232}^{\prime\prime 1}$	40000

Table 20: Continued.

$\mathbf{S}''^{2}_{131}$	25000
$\mathbf{S}''^{2}_{132}$	17000
$\mathbf{S}''^{2}_{231}$	20000
$\mathbf{S}''^{2}_{232}$	15000
$\mathbf{S}''^{3}_{131}$	120000
$\mathbf{S}''^{3}_{132}$	80000
$\mathbf{S}''^{3}_{231}$	140000
$\mathbf{S}''^{3}_{232}$	80000
$\mathbf{S}''^{1}_{141}$	30000
$\mathbf{S}''^{1}_{142}$	20000
$\mathbf{S}''^{1}_{241}$	40000
$\mathbf{S}''^{1}_{242}$	40000
$\mathbf{S}''^{2}_{141}$	25000
$\mathbf{S}''^{2}_{142}$	17000
$\mathbf{S}''^{2}_{241}$	20000
$\mathbf{S}''^{2}_{242}$	15000
$\mathbf{S}''^{3}_{141}$	120000
$\mathbf{S}''^{3}_{142}$	80000
$\mathbf{S}''^{3}_{241}$	140000
$\mathbf{S}''^{3}_{242}$	80000

Table 21: Values of the input parameter $\mathbf{S}'''^{\mathbf{o}}_{\mathbf{j}'\mathbf{kr}}$.

$\mathbf{S}'''^{1}_{111}$	45000
$\mathbf{S}'''^{1}_{112}$	25000
$\mathbf{S}'''^{2}_{111}$	30000
$\mathbf{S}'''^{2}_{112}$	20000
$\mathbf{S}'''^{3}_{111}$	125000
$\mathbf{S}'''^{3}_{112}$	85000
$\mathbf{S}'''^{1}_{121}$	45000
$\mathbf{S}'''^{1}_{122}$	25000
$\mathbf{S}'''^{2}_{121}$	30000
$\mathbf{S}'''^{2}_{122}$	20000
$\mathbf{S}'''^{3}_{121}$	125000
$\mathbf{S}'''^{3}_{122}$	85000
$\mathbf{S}'''^{1}_{131}$	35000
$\mathbf{S}'''^{1}_{132}$	30000
$\mathbf{S}'''^{2}_{131}$	25000
$\mathbf{S}'''^{2}_{132}$	25000
$\mathbf{S}'''^{3}_{131}$	145000
$\mathbf{S}'''^{3}_{132}$	90000
$\mathbf{S}'''^{1}_{141}$	45000
$\mathbf{S}'''^{1}_{142}$	30000
$\mathbf{S}'''^{2}_{141}$	25000
$\mathbf{S}'''^{2}_{142}$	25000
$\mathbf{S}'''^{3}_{141}$	145000
$\mathbf{S}'''^{3}_{142}$	90000

Table 22: Values of the input parameter $\mathbf{B}^{\mathbf{po}}_{\mathbf{j}'\mathbf{k}}$.

$\mathbf{B}^{11}_{11}$	0.4106
$\mathbf{B}^{21}_{11}$	0.7835
$\mathbf{B}^{31}_{11}$	0.2370
$\mathbf{B}^{12}_{11}$	0.2370
$\mathbf{B}^{22}_{11}$	0.5663
$\mathbf{B}^{32}_{11}$	0.5204
$\mathbf{B}^{13}_{11}$	0.3944
$\mathbf{B}^{23}_{11}$	0.3810
$\mathbf{B}^{33}_{11}$	0.4445
$\mathbf{B}^{11}_{12}$	0.3457
$\mathbf{B}^{21}_{12}$	0.6309
$\mathbf{B}^{31}_{12}$	0.6495
$\mathbf{B}^{12}_{12}$	0.6495
$\mathbf{B}^{22}_{12}$	0.2831
$\mathbf{B}^{32}_{12}$	0.3609
$\mathbf{B}^{13}_{12}$	0.7154
$\mathbf{B}^{23}_{12}$	0.5128
$\mathbf{B}^{33}_{12}$	0.3395
$\mathbf{B}^{11}_{13}$	0.3205
$\mathbf{B}^{21}_{13}$	0.3683
$\mathbf{B}^{31}_{13}$	0.0415
$\mathbf{B}^{12}_{13}$	0.0415
$\mathbf{B}^{22}_{13}$	0.8293
$\mathbf{B}^{32}_{13}$	0.8749
$\mathbf{B}^{13}_{13}$	0.2746
$\mathbf{B}^{23}_{13}$	0.3784
$\mathbf{B}^{33}_{13}$	0.7580
$\mathbf{B}^{11}_{14}$	0.6274
$\mathbf{B}^{21}_{14}$	0.1692
$\mathbf{B}^{31}_{14}$	0.1997
$\mathbf{B}^{12}_{14}$	0.1997
$\mathbf{B}^{22}_{14}$	0.3
$\mathbf{B}^{32}_{14}$	0.2655
$\mathbf{B}^{13}_{14}$	0.7265
$\mathbf{B}^{23}_{14}$	0.9051
$\mathbf{B}^{33}_{14}$	0.4120

Table 23: Values of the input parameter $\mathbf{Q}^{\mathbf{po}}_{\mathbf{iL}}, \mathbf{Q}^{\mathbf{po}}_{\mathbf{iH}}, \mathbf{Q}^{\mathbf{po}}_{\mathbf{iU}}$.

$\mathbf{Q}^{11}_{1L}$	412848
$\mathbf{Q}^{12}_{1L}$	16451
$\mathbf{Q}^{13}_{1L}$	5538
$\mathbf{Q}^{21}_{1L}$	682154
$\mathbf{Q}^{22}_{1L}$	29455
$\mathbf{Q}^{23}_{1L}$	6837
$\mathbf{Q}^{31}_{1L}$	1083510
$\mathbf{Q}^{32}_{1L}$	52398
$\mathbf{Q}^{33}_{1L}$	12412
$\mathbf{Q}^{11}_{1H}$	522060
$\mathbf{Q}^{12}_{1H}$	26103
$\mathbf{Q}^{13}_{1H}$	6525
$\mathbf{Q}^{21}_{1H}$	783091
$\mathbf{Q}^{22}_{1H}$	39154
$\mathbf{Q}^{23}_{1H}$	9788
$\mathbf{Q}^{31}_{1H}$	1305152
$\mathbf{Q}^{32}_{1H}$	65257
$\mathbf{Q}^{33}_{1H}$	16314
$\mathbf{Q}^{11}_{1U}$	612542
$\mathbf{Q}^{12}_{1U}$	35761
$\mathbf{Q}^{13}_{1U}$	8025
$\mathbf{Q}^{21}_{1U}$	894840
$\mathbf{Q}^{22}_{1U}$	48468
$\mathbf{Q}^{23}_{1U}$	12235
$\mathbf{Q}^{31}_{1U}$	1487821
$\mathbf{Q}^{32}_{1U}$	71245
$\mathbf{Q}^{33}_{1U}$	21371

Table 24: Values of the input parameter $\varphi_{\mathbf{j}}^{\mathbf{po}}$.

φ_1^{11}	0.22
φ_1^{21}	0.3
φ_1^{31}	0.45
φ_1^{12}	0.17
φ_1^{22}	0.09
φ_1^{32}	0.07
φ_1^{13}	0.19
φ_1^{23}	0.14
φ_1^{33}	0.18
φ_2^{11}	0.31
φ_2^{21}	0.19
φ_2^{31}	0.31
φ_2^{12}	0.15
φ_2^{22}	0.07
φ_2^{32}	0.12
φ_2^{13}	0.08
φ_2^{23}	0.16
φ_2^{33}	0.09

Table 25: Values of the input parameter $\varphi_{j'}^{'\mathbf{po}}$.

$\varphi_1^{'11}$	0.29
$\varphi_1^{'21}$	0.19
$\varphi_1^{'31}$	0.18
$\varphi_1^{'12}$	0.29
$\varphi_1^{'22}$	0.19
$\varphi_1^{'32}$	0.18
$\varphi_1^{'13}$	0.21
$\varphi_1^{'23}$	0.39
$\varphi_1^{'33}$	0.14

Table 26: Values of the input parameter $\varphi_{\mathbf{k}}^{''\mathbf{po}}$.

$\varphi_1^{''11}$	0.61
$\varphi_2^{''11}$	0.51
$\varphi_3^{''11}$	0.66
$\varphi_4^{''11}$	0.71
$\varphi_1^{''12}$	0.09
$\varphi_2^{''12}$	0.08
$\varphi_3^{''12}$	0.07
$\varphi_4^{''12}$	0.15
$\varphi_1^{''13}$	0.12
$\varphi_2^{''13}$	0.28
$\varphi_3^{''13}$	0.19
$\varphi_4^{''13}$	0.37
$\varphi_1^{''21}$	0.51
$\varphi_2^{''21}$	0.47
$\varphi_3^{''21}$	0.62
$\varphi_4^{''21}$	0.37
$\varphi_1^{''22}$	0.28
$\varphi_2^{''22}$	0.19
$\varphi_3^{''22}$	0.09
$\varphi_4^{''22}$	0.17
$\varphi_1^{''23}$	0.18
$\varphi_2^{''23}$	0.29
$\varphi_3^{''23}$	0.37
$\varphi_4^{''23}$	0.49
$\varphi_1^{''31}$	0.38
$\varphi_2^{''31}$	0.61
$\varphi_3^{''31}$	0.52

Table 26: Continued.

$\varphi_4^{''31}$	0.41
$\varphi_1^{''32}$	0.08
$\varphi_2^{''32}$	0.19
$\varphi_3^{''32}$	0.28
$\varphi_4^{''32}$	0.36
$\varphi_1^{''33}$	0.67
$\varphi_2^{''33}$	0.41
$\varphi_3^{''33}$	0.59
$\varphi_4^{''33}$	0.44

Table 27: Values of the input parameter $\mathbf{b}_{\mathbf{j}}^{\mathbf{po}}$.

$\mathbf{b}_1^{11}$	0.22
$\mathbf{b}_1^{21}$	0.11
$\mathbf{b}_1^{31}$	0.91
$\mathbf{b}_1^{12}$	0.35
$\mathbf{b}_1^{22}$	0.34
$\mathbf{b}_1^{32}$	0.87
$\mathbf{b}_1^{13}$	0.24
$\mathbf{b}_1^{23}$	0.08
$\mathbf{b}_1^{33}$	0.74
$\mathbf{b}_2^{11}$	0.53
$\mathbf{b}_2^{21}$	0.37
$\mathbf{b}_2^{31}$	0.33
$\mathbf{b}_2^{12}$	0.78
$\mathbf{b}_2^{22}$	0.87
$\mathbf{b}_2^{32}$	0.21
$\mathbf{b}_2^{13}$	0.87
$\mathbf{b}_2^{23}$	0.14
$\mathbf{b}_2^{33}$	0.71

Table 28: Values of the input parameter $\mathbf{b}_{j'}^{\mathbf{po}}$.

$\mathbf{b}_1^{11}$	0.28
$\mathbf{b}_1^{21}$	0.16
$\mathbf{b}_1^{31}$	0.4
$\mathbf{b}_1^{12}$	0.42
$\mathbf{b}_1^{22}$	0.37
$\mathbf{b}_1^{32}$	0.32
$\mathbf{b}_1^{13}$	0.072
$\mathbf{b}_1^{23}$	0.22
$\mathbf{b}_1^{33}$	0.61

Table 29: Values of the input parameter $\mathbf{c}_{\mathbf{k}}^{\mathbf{po}}$.

$\mathbf{c}_1^{11}$	0.09
$\mathbf{c}_2^{11}$	0.13
$\mathbf{c}_3^{11}$	0.45
$\mathbf{c}_4^{11}$	0.17
$\mathbf{c}_1^{12}$	0.8
$\mathbf{c}_2^{12}$	0.02
$\mathbf{c}_3^{12}$	0.06
$\mathbf{c}_4^{12}$	0.3
$\mathbf{c}_1^{13}$	0.81
$\mathbf{c}_2^{13}$	0.22
$\mathbf{c}_3^{13}$	0.48
$\mathbf{c}_4^{13}$	0.24
$\mathbf{c}_1^{21}$	0.21
$\mathbf{c}_2^{21}$	0.36

Table 29: Continued.

$\mathbf{c}_3^{21}$	0.21
$\mathbf{c}_4^{21}$	0.19
$\mathbf{c}_1^{22}$	0.11
$\mathbf{c}_2^{22}$	0.75
$\mathbf{c}_3^{22}$	0.31
$\mathbf{c}_4^{22}$	0.22
$\mathbf{c}_1^{23}$	0.08
$\mathbf{c}_2^{23}$	0.32
$\mathbf{c}_3^{23}$	0.41
$\mathbf{c}_4^{23}$	0.10
$\mathbf{c}_1^{31}$	0.13
$\mathbf{c}_2^{31}$	0.14
$\mathbf{c}_3^{31}$	0.51
$\mathbf{c}_4^{31}$	0.42
$\mathbf{c}_1^{32}$	0.11
$\mathbf{c}_2^{32}$	0.62
$\mathbf{c}_3^{32}$	0.34
$\mathbf{c}_4^{32}$	0.14
$\mathbf{c}_1^{33}$	0.52
$\mathbf{c}_2^{33}$	0.38
$\mathbf{c}_3^{33}$	0.21
$\mathbf{c}_4^{33}$	0.12

Table 30: Values of the input parameter $\mathbf{d}_\mathbf{k}^{\mathbf{po}}$.

$\mathbf{d}_1^{11}$	0.56
$\mathbf{d}_2^{11}$	0.61
$\mathbf{d}_3^{11}$	0.67
$\mathbf{d}_4^{11}$	0.23
$\mathbf{d}_1^{12}$	0.38
$\mathbf{d}_2^{12}$	0.01
$\mathbf{d}_3^{12}$	0.58
$\mathbf{d}_4^{12}$	0.07
$\mathbf{d}_1^{13}$	0.03
$\mathbf{d}_2^{13}$	0.64
$\mathbf{d}_3^{13}$	0.13
$\mathbf{d}_4^{13}$	0.29
$\mathbf{d}_1^{21}$	0.28
$\mathbf{d}_2^{21}$	0.56
$\mathbf{d}_3^{21}$	0.57
$\mathbf{d}_4^{21}$	0.92
$\mathbf{d}_1^{22}$	0.94
$\mathbf{d}_2^{22}$	0.64
$\mathbf{d}_3^{22}$	0.60
$\mathbf{d}_4^{22}$	0.60
$\mathbf{d}_1^{23}$	0.56
$\mathbf{d}_2^{23}$	0.12
$\mathbf{d}_3^{23}$	0.54
$\mathbf{d}_4^{23}$	0.16
$\mathbf{d}_1^{31}$	0.27
$\mathbf{d}_2^{31}$	0.05
$\mathbf{d}_3^{31}$	0.61
$\mathbf{d}_4^{31}$	0.72
$\mathbf{d}_1^{32}$	0.2
$\mathbf{d}_2^{32}$	0.05
$\mathbf{d}_3^{32}$	0.44
$\mathbf{d}_4^{32}$	0.35
$\mathbf{d}_1^{33}$	0.28
$\mathbf{d}_2^{33}$	0.32
$\mathbf{d}_3^{33}$	0.23
$\mathbf{d}_4^{33}$	0.56

Table 31: Values of the input parameter $\mathbf{e}_\mathbf{k}^{\mathbf{po}}$.

$\mathbf{e}_1^{11}$	0.75
$\mathbf{e}_2^{11}$	0.55
$\mathbf{e}_3^{11}$	0.25
$\mathbf{e}_4^{11}$	0.04
$\mathbf{e}_1^{12}$	0.05
$\mathbf{e}_2^{12}$	0.45
$\mathbf{e}_3^{12}$	0.36
$\mathbf{e}_4^{12}$	0.28
$\mathbf{e}_1^{13}$	0.41
$\mathbf{e}_2^{13}$	0.5
$\mathbf{e}_3^{13}$	0.5
$\mathbf{e}_4^{13}$	0.61
$\mathbf{e}_1^{21}$	0.5
$\mathbf{e}_2^{21}$	0.32
$\mathbf{e}_3^{21}$	0.8
$\mathbf{e}_4^{21}$	0.67
$\mathbf{e}_1^{22}$	0.97
$\mathbf{e}_2^{22}$	0.83
$\mathbf{e}_3^{22}$	0.5
$\mathbf{e}_4^{22}$	0.38
$\mathbf{e}_1^{23}$	0.19
$\mathbf{e}_2^{23}$	0.11
$\mathbf{e}_3^{23}$	0.36
$\mathbf{e}_4^{23}$	0.36
$\mathbf{e}_1^{31}$	0.24
$\mathbf{e}_2^{31}$	0.75
e_3^{31}	0.46
$\mathbf{e}_4^{31}$	0.27
$\mathbf{e}_1^{32}$	0.64
$\mathbf{e}_2^{32}$	0.67
$\mathbf{e}_3^{32}$	0.05
$\mathbf{e}_4^{32}$	0.28
$\mathbf{e}_1^{33}$	0.2
$\mathbf{e}_2^{33}$	0.57
$\mathbf{e}_3^{33}$	0.58
$\mathbf{e}_4^{33}$	0.24

Table 32: Control parameters.

MOEA/D optimization	Population size	20
	Reservoir	15
	Number of objectives	3
	Maximum iteration	250

5.1. The Pseudocode of the Proposed Algorithm

A population of N point $x^1, \ldots, x^N$, where x^i is the current solution to the *i*th subproblem.

Objective function $F^1, \ldots, F^N$, where F^i is the *F*-value of x^i, that is, $F^i = F(x^i)$.

Initialize max iteration, that is, max it.

W *hile (t < Max it number of iterations.*

For every solution in population, that is,. i = 1,. . ., N.

(i) *Initialize position of solution based on step 3-3-1-1-1.*

(ii) *Compute the Euclidean distances between any two weight vectors and then work out the T and closest weight vectors to each weight vector. For each*

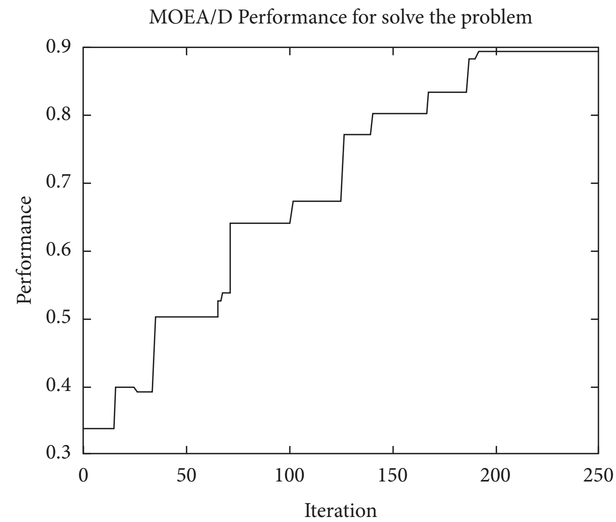

Figure 2: Performance trend of the algorithm.

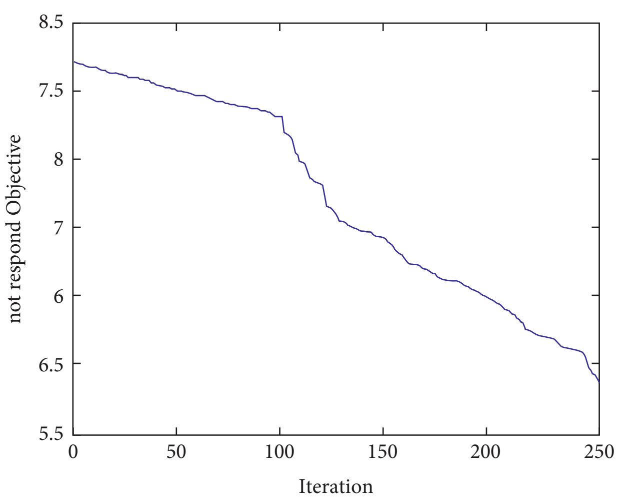

Figure 3: Not respond demand (first objective) considering the iteration of the algorithm.

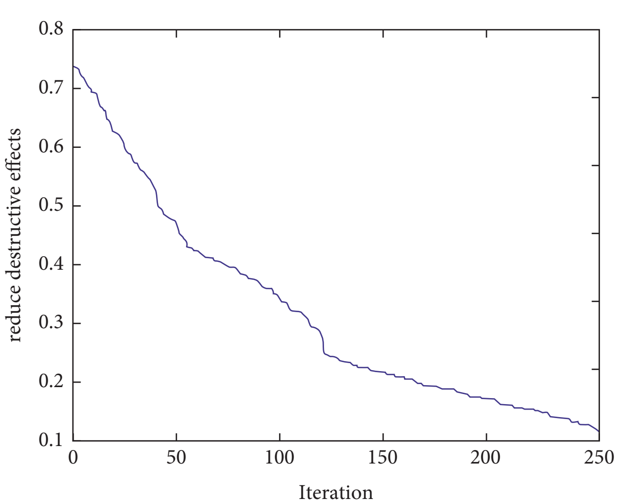

Figure 4: Destructive environmental effects in the supply chain (the second objective) considering the iteration of the algorithm.

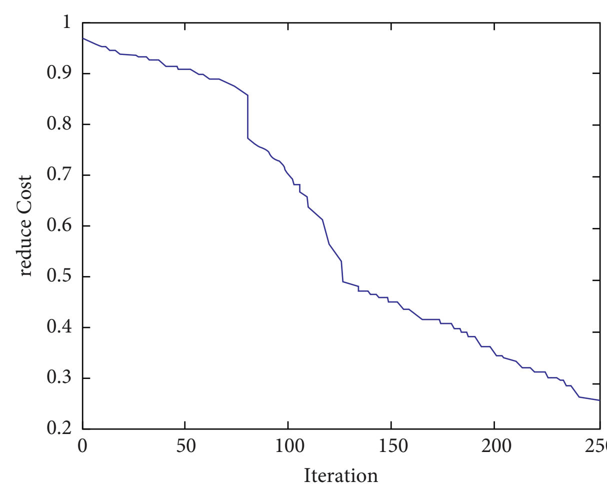

Figure 5: Costs (the third objective) considering the iteration of the algorithm.

$i = 1, \ldots,$ N, set $B(i) = \{i_1 \ldots . i_T\}$ where-$\{\lambda^{i_1}, \ldots, \lambda^{i_T}\}$are T closest weight vectors to λ^i.

(iii) *Evaluate fitness of solution based on step. 3-3-1-1-2.*

(iv) *$z = \{z_1, \ldots, z_m\}^T$ where z_i is the best value found so far objective f_i (three-objective) and T is the number of the weight vectors in the neighborhood of each weight vector.*

(v) *An external repository (ER) which is used to store nondominated solutions found during the search.*

(vi) *Select a solution randomly and perform single point mutation.*

(vii) *Updating locations/solutions step 3-3-1-1-2 using a leader from ER based on best, the best solution is extracted via previous phase.*

End for.

For each $j = 1, \ldots, m$.

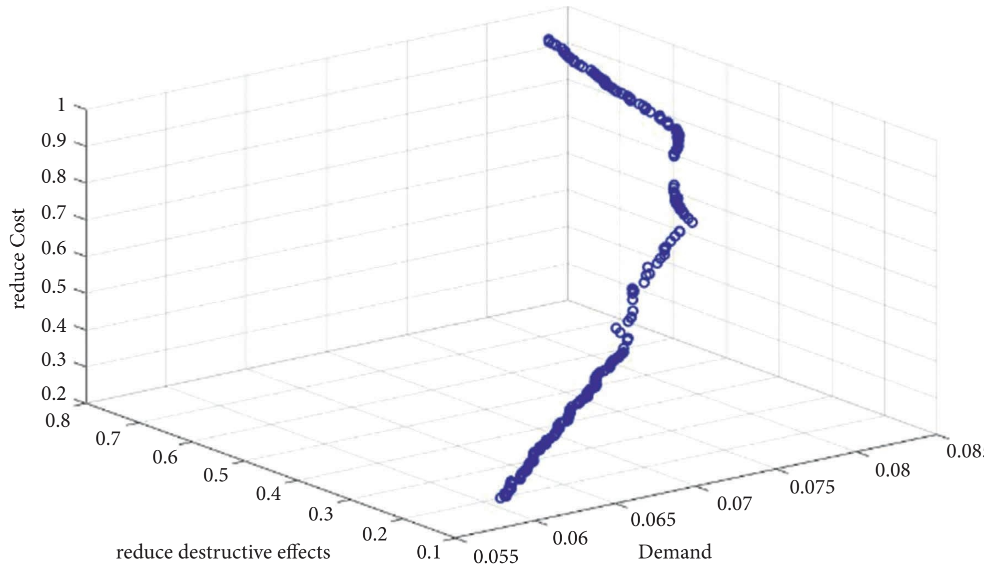

Figure 6: Pareto archive of the three objectives.

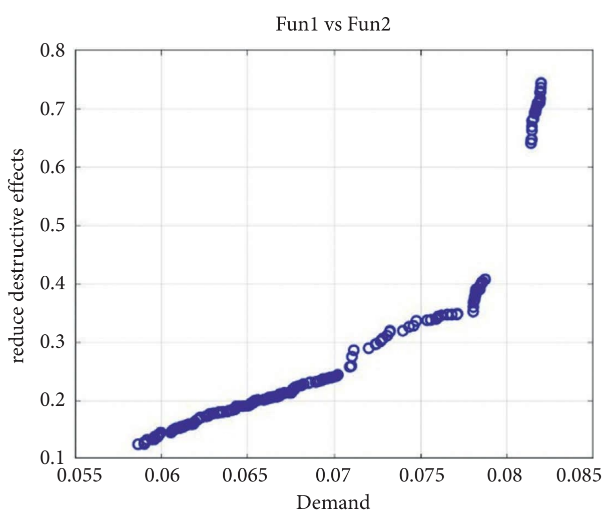

Figure 7: Pareto archive from the first and second objective functions.

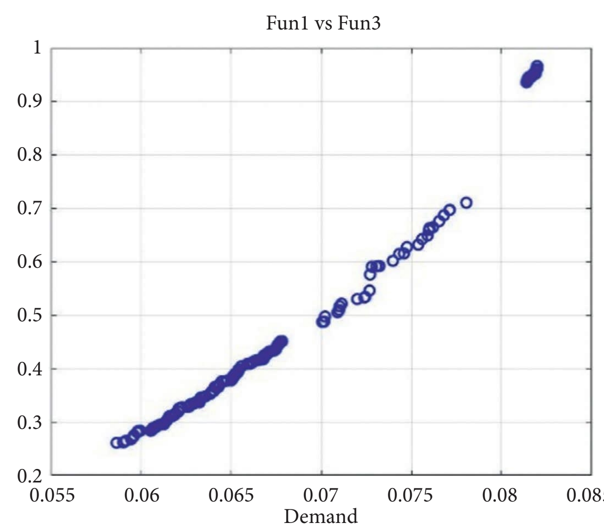

Figure 8: Pareto archive from the first and third objective functions.

(viii) *Update* $z = \{z_1, \ldots, z_m\}^T s$ *: for each* $j = 1, \ldots, m$, *if* $z_j < f_j(y')$, then set $z_j = f_j(y')$.

(ix) *Update position so if* $j \in B(i)$. if $(\max \lambda^i \{ f_j(y') - Z_t^* \} \leq \max \lambda^i \{ f_j(x^j) - Z_t^* \})$, *then set* $x^j = y'$ *and* $F^j = F(y')$.

End f*or.*

Recalculate from (ER) of all the vectors dominated by $F(y')$.

Recalculate fitness of all solutions.

Rank the solution/solution and find the current best x^*.

End while.

Results: best solution.

6. Result

One way to ensure the accuracy of the response is to analyze the performance of the optimization algorithms during each iteration (algorithm implementation). The response of performance accuracy is often normal within [0-1], with 1 denoting the 100% accuracy of the algorithm and 0 indicating inaccuracy in finding the optimal response to the problem. Therefore, the closer the algorithm performance is to 1, the more precise it is, and consequently, the more reliable the responses are. In addition, if an algorithm has an upward trend during each implementation (iteration) in terms of performance accuracy, it indicates that the algorithm is highly capable of solving the problem. Figure 2 shows the performance accuracy of the algorithm. As can be

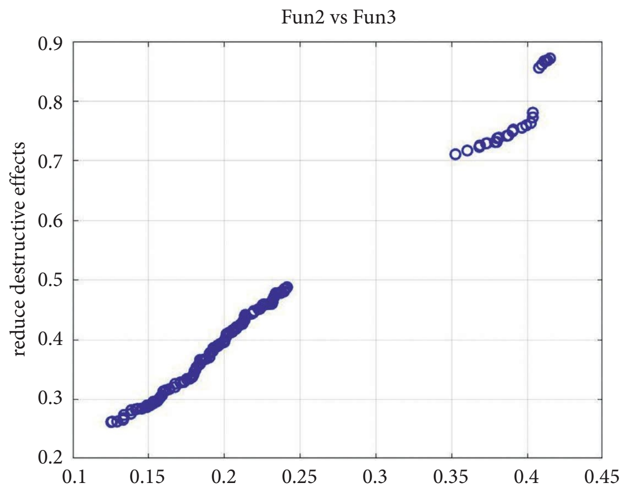

Figure 9: Pareto archive from the second and third objective functions.

Table 33: Values of the decision variable x_{ijr}^{po}.

$\mathbf{x}_{111}^{11}$	14938
$\mathbf{x}_{111}^{12}$	580
$\mathbf{x}_{111}^{13}$	154
$\mathbf{x}_{121}^{11}$	16296
$\mathbf{x}_{121}^{12}$	871
$\mathbf{x}_{121}^{13}$	103
$\mathbf{x}_{112}^{11}$	13276
$\mathbf{x}_{112}^{12}$	382
x_{112}^{13}	62
$\mathbf{x}_{122}^{11}$	8359
$\mathbf{x}_{122}^{12}$	313
$\mathbf{x}_{122}^{13}$	59
$\mathbf{x}_{111}^{21}$	14417
$\mathbf{x}_{111}^{22}$	1307
$\mathbf{x}_{111}^{23}$	122
$\mathbf{x}_{121}^{21}$	22655
$\mathbf{x}_{121}^{22}$	532
$\mathbf{x}_{121}^{23}$	183
$\mathbf{x}_{112}^{21}$	11357
$\mathbf{x}_{112}^{22}$	501
$\mathbf{x}_{112}^{23}$	112
$\mathbf{x}_{122}^{21}$	7150
$\mathbf{x}_{122}^{22}$	410
$\mathbf{x}_{122}^{23}$	107
$\mathbf{x}_{111}^{31}$	37063
$\mathbf{x}_{111}^{32}$	1549
$\mathbf{x}_{111}^{33}$	132
$\mathbf{x}_{121}^{31}$	33975
$\mathbf{x}_{121}^{32}$	1033
$\mathbf{x}_{121}^{33}$	199
$\mathbf{x}_{112}^{31}$	22452
$\mathbf{x}_{112}^{32}$	491
$\mathbf{x}_{112}^{33}$	160
$\mathbf{x}_{122}^{31}$	14136
$\mathbf{x}_{122}^{32}$	401
$\mathbf{x}_{122}^{33}$	168
$\mathbf{x}_{211}^{11}$	10864
$\mathbf{x}_{211}^{12}$	354
$\mathbf{x}_{211}^{13}$	86

Table 33: Continued.

$\mathbf{x}_{221}^{11}$	9506
$\mathbf{x}_{221}^{12}$	419
$\mathbf{x}_{221}^{13}$	74
$\mathbf{x}_{212}^{11}$	6883
$\mathbf{x}_{212}^{12}$	295
$\mathbf{x}_{212}^{13}$	35
$\mathbf{x}_{222}^{11}$	7375
$\mathbf{x}_{222}^{12}$	295
$\mathbf{x}_{222}^{13}$	50
$\mathbf{x}_{211}^{21}$	13387
$\mathbf{x}_{211}^{22}$	871
$\mathbf{x}_{211}^{23}$	88
$\mathbf{x}_{221}^{21}$	24715
$\mathbf{x}_{221}^{22}$	726
$\mathbf{x}_{221}^{23}$	108
$\mathbf{x}_{212}^{21}$	6309
$\mathbf{x}_{212}^{22}$	273
$\mathbf{x}_{212}^{23}$	91
$\mathbf{x}_{222}^{21}$	5888
$\mathbf{x}_{222}^{22}$	387
$\mathbf{x}_{222}^{23}$	85
$\mathbf{x}_{211}^{31}$	24709
$\mathbf{x}_{211}^{32}$	861
$\mathbf{x}_{211}^{33}$	118
$\mathbf{x}_{221}^{31}$	21620
$\mathbf{x}_{221}^{32}$	918
$\mathbf{x}_{221}^{33}$	110
$\mathbf{x}_{212}^{31}$	11641
$\mathbf{x}_{212}^{32}$	379
$\mathbf{x}_{212}^{33}$	112
$\mathbf{x}_{222}^{31}$	1273
$\mathbf{x}_{222}^{32}$	267
$\mathbf{x}_{222}^{33}$	136
$\mathbf{x}_{311}^{11}$	7469
$\mathbf{x}_{311}^{12}$	484
$\mathbf{x}_{311}^{13}$	91
$\mathbf{x}_{321}^{11}$	8827
$\mathbf{x}_{321}^{12}$	516
$\mathbf{x}_{321}^{13}$	63
$\mathbf{x}_{312}^{11}$	7867
$\mathbf{x}_{312}^{12}$	208
$\mathbf{x}_{312}^{13}$	41
$\mathbf{x}_{322}^{11}$	5408
$\mathbf{x}_{322}^{12}$	243
$\mathbf{x}_{322}^{13}$	47
$\mathbf{x}_{311}^{21}$	11327
$\mathbf{x}_{311}^{22}$	629
$\mathbf{x}_{311}^{23}$	74
$\mathbf{x}_{321}^{21}$	16476
$\mathbf{x}_{321}^{22}$	774
$\mathbf{x}_{321}^{23}$	102
$\mathbf{x}_{312}^{21}$	6730
$\mathbf{x}_{312}^{22}$	387
$\mathbf{x}_{312}^{23}$	64
$\mathbf{x}_{322}^{21}$	4626
$\mathbf{x}_{322}^{22}$	319
$\mathbf{x}_{322}^{23}$	75
$\mathbf{x}_{311}^{31}$	20076
$\mathbf{x}_{311}^{32}$	746
$\mathbf{x}_{311}^{33}$	95
$\mathbf{x}_{321}^{31}$	16987
$\mathbf{x}_{321}^{32}$	631
$\mathbf{x}_{321}^{33}$	81

Table 33: Continued.

$\mathbf{x}_{312}^{31}$	12473
$\mathbf{x}_{312}^{32}$	312
$\mathbf{x}_{312}^{33}$	128
$\mathbf{x}_{322}^{31}$	9147
$\mathbf{x}_{322}^{32}$	379
$\mathbf{x}_{322}^{33}$	96

Table 34: Values of the decision variable $x_{ij'r}^{\prime po}$.

$\mathbf{x}_{111}^{\prime 11}$	42792
$\mathbf{x}_{111}^{\prime 12}$	1573
$\mathbf{x}_{111}^{\prime 13}$	485
$\mathbf{x}_{112}^{\prime 11}$	32282
$\mathbf{x}_{112}^{\prime 12}$	1552
$\mathbf{x}_{112}^{\prime 13}$	357
$\mathbf{x}_{111}^{\prime 21}$	48602
$\mathbf{x}_{111}^{\prime 22}$	2204
$\mathbf{x}_{111}^{\prime 23}$	709
$\mathbf{x}_{112}^{\prime 21}$	50084
$\mathbf{x}_{112}^{\prime 22}$	1451
$\mathbf{x}_{112}^{\prime 23}$	589
$\mathbf{x}_{111}^{\prime 31}$	89892
$\mathbf{x}_{111}^{\prime 32}$	4183
$\mathbf{x}_{111}^{\prime 33}$	680
$\mathbf{x}_{112}^{\prime 31}$	59420
$\mathbf{x}_{112}^{\prime 32}$	1671
$\mathbf{x}_{112}^{\prime 33}$	500
$\mathbf{x}_{211}^{\prime 11}$	33399
$\mathbf{x}_{211}^{\prime 12}$	1284
$\mathbf{x}_{211}^{\prime 13}$	461
$\mathbf{x}_{212}^{\prime 11}$	25196
$\mathbf{x}_{212}^{\prime 12}$	1422
$\mathbf{x}_{212}^{\prime 13}$	311
$\mathbf{x}_{211}^{\prime 21}$	36748
$\mathbf{x}_{211}^{\prime 22}$	1798
$\mathbf{x}_{211}^{\prime 23}$	674
$\mathbf{x}_{212}^{\prime 21}$	43663
$\mathbf{x}_{212}^{\prime 22}$	1249
$\mathbf{x}_{212}^{\prime 23}$	408
$\mathbf{x}_{211}^{\prime 31}$	63582
$\mathbf{x}_{211}^{\prime 32}$	3412
$\mathbf{x}_{211}^{\prime 33}$	561
$\mathbf{x}_{212}^{\prime 31}$	51802
$\mathbf{x}_{212}^{\prime 32}$	1570
$\mathbf{x}_{212}^{\prime 33}$	449
$\mathbf{x}_{311}^{\prime 11}$	28180
$\mathbf{x}_{311}^{\prime 12}$	1284
$\mathbf{x}_{311}^{\prime 13}$	267
$\mathbf{x}_{312}^{\prime 11}$	21259
$\mathbf{x}_{312}^{\prime 12}$	1336
$\mathbf{x}_{312}^{\prime 13}$	247
$\mathbf{x}_{311}^{\prime 21}$	33191
$\mathbf{x}_{311}^{\prime 22}$	1798
$\mathbf{x}_{311}^{\prime 23}$	390
$\mathbf{x}_{312}^{\prime 21}$	34673
$\mathbf{x}_{312}^{\prime 22}$	1330

Table 34: Continued.

$\mathbf{x}_{312}^{\prime 23}$	514
$\mathbf{x}_{311}^{\prime 31}$	65774
$\mathbf{x}_{311}^{\prime 32}$	3412
$\mathbf{x}_{311}^{\prime 33}$	459
$\mathbf{x}_{312}^{\prime 31}$	41137
$\mathbf{x}_{312}^{\prime 32}$	1823
$\mathbf{x}_{312}^{\prime 33}$	333

Table 35: Values of the decision variable $x_{jkr}^{\prime\prime po}$.

$\mathbf{x}_{111}^{\prime\prime 11}$	8487
$\mathbf{x}_{211}^{\prime\prime 11}$	29258
$\mathbf{x}_{111}^{\prime\prime 12}$	403
$\mathbf{x}_{211}^{\prime\prime 12}$	194
$\mathbf{x}_{111}^{\prime\prime 13}$	71
$\mathbf{x}_{211}^{\prime\prime 13}$	65
$\mathbf{x}_{112}^{\prime\prime 11}$	10080
$\mathbf{x}_{212}^{\prime\prime 11}$	20718
$\mathbf{x}_{112}^{\prime\prime 12}$	320
$\mathbf{x}_{212}^{\prime\prime 12}$	240
$\mathbf{x}_{112}^{\prime\prime 13}$	34
$\mathbf{x}_{212}^{\prime\prime 13}$	46
$\mathbf{x}_{111}^{\prime\prime 21}$	16476
$\mathbf{x}_{211}^{\prime\prime 21}$	15476
$\mathbf{x}_{111}^{\prime\prime 22}$	726
$\mathbf{x}_{211}^{\prime\prime 22}$	673
$\mathbf{x}_{111}^{\prime\prime 23}$	204
$\mathbf{x}_{211}^{\prime\prime 23}$	189
$\mathbf{x}_{112}^{\prime\prime 21}$	12618
$\mathbf{x}_{212}^{\prime\prime 21}$	11618
$\mathbf{x}_{112}^{\prime\prime 22}$	341
$\mathbf{x}_{212}^{\prime\prime 22}$	300
$\mathbf{x}_{112}^{\prime\prime 23}$	160
$\mathbf{x}_{212}^{\prime\prime 23}$	160
$\mathbf{x}_{111}^{\prime\prime 31}$	17759
$\mathbf{x}_{211}^{\prime\prime 31}$	16454
$\mathbf{x}_{111}^{\prime\prime 32}$	717
$\mathbf{x}_{211}^{\prime\prime 32}$	700
$\mathbf{x}_{111}^{\prime\prime 33}$	118
$\mathbf{x}_{211}^{\prime\prime 33}$	100
$\mathbf{x}_{112}^{\prime\prime 31}$	11641
$\mathbf{x}_{212}^{\prime\prime 31}$	11541
$\mathbf{x}_{112}^{\prime\prime 32}$	312
$\mathbf{x}_{212}^{\prime\prime 32}$	300
$\mathbf{x}_{212}^{\prime\prime 33}$	112
$\mathbf{x}_{212}^{\prime\prime 33}$	112
$\mathbf{x}_{121}^{\prime\prime 11}$	10864
$\mathbf{x}_{221}^{\prime\prime 11}$	2117
$\mathbf{x}_{121}^{\prime\prime 12}$	516
$\mathbf{x}_{221}^{\prime\prime 12}$	315
$\mathbf{x}_{121}^{\prime\prime 13}$	80
$\mathbf{x}_{221}^{\prime\prime 13}$	76
$\mathbf{x}_{122}^{\prime\prime 11}$	5654

Table 35: Continued.

$\mathbf{x}_{222}^{\prime\prime 11}$	2178
$\mathbf{x}_{122}^{\prime\prime 12}$	184
$\mathbf{x}_{222}^{\prime\prime 12}$	84
$\mathbf{x}_{122}^{\prime\prime 13}$	40
$\mathbf{x}_{222}^{\prime\prime 13}$	50
$\mathbf{x}_{121}^{\prime\prime 21}$	13384
$\mathbf{x}_{221}^{\prime\prime 21}$	13267
$\mathbf{x}_{121}^{\prime\prime 22}$	629
$\mathbf{x}_{221}^{\prime\prime 22}$	679
$\mathbf{x}_{121}^{\prime\prime 23}$	163
$\mathbf{x}_{221}^{\prime\prime 23}$	178
$\mathbf{x}_{122}^{\prime\prime 21}$	111777
$\mathbf{x}_{222}^{\prime\prime 21}$	111756
$\mathbf{x}_{122}^{\prime\prime 22}$	273
$\mathbf{x}_{222}^{\prime\prime 22}$	314
$\mathbf{x}_{122}^{\prime\prime 23}$	128
$\mathbf{x}_{222}^{\prime\prime 23}$	128
$\mathbf{x}_{121}^{\prime\prime 31}$	24709
$\mathbf{x}_{221}^{\prime\prime 31}$	23521
$\mathbf{x}_{121}^{\prime\prime 32}$	918
$\mathbf{x}_{211}^{\prime\prime 32}$	935
$\mathbf{x}_{121}^{\prime\prime 33}$	92
$\mathbf{x}_{221}^{\prime\prime 33}$	110
$\mathbf{x}_{122}^{\prime\prime 31}$	12473
$\mathbf{x}_{222}^{\prime\prime 31}$	11545
$\mathbf{x}_{122}^{\prime\prime 32}$	334
$\mathbf{x}_{222}^{\prime\prime 32}$	350
$\mathbf{x}_{122}^{\prime\prime 33}$	120
$\mathbf{x}_{222}^{\prime\prime 33}$	80
$\mathbf{x}_{131}^{\prime\prime 11}$	7129
$\mathbf{x}_{231}^{\prime\prime 11}$	13737
$\mathbf{x}_{131}^{\prime\prime 12}$	338
$\mathbf{x}_{231}^{\prime\prime 12}$	328
$\mathbf{x}_{131}^{\prime\prime 13}$	60
$\mathbf{x}_{231}^{\prime\prime 13}$	67
$\mathbf{x}_{132}^{\prime\prime 11}$	5654
$\mathbf{x}_{232}^{\prime\prime 11}$	152
$\mathbf{x}_{132}^{\prime\prime 12}$	210
$\mathbf{x}_{232}^{\prime\prime 12}$	310
$\mathbf{x}_{132}^{\prime\prime 13}$	35
$\mathbf{x}_{232}^{\prime\prime 13}$	30
$\mathbf{x}_{131}^{\prime\prime 21}$	11327
$\mathbf{x}_{231}^{\prime\prime 21}$	10654
$\mathbf{x}_{131}^{\prime\prime 22}$	580
$\mathbf{x}_{231}^{\prime\prime 22}$	440
$\mathbf{x}_{131}^{\prime\prime 23}$	176
$\mathbf{x}_{231}^{\prime\prime 23}$	131
$\mathbf{x}_{132}^{\prime\prime 21}$	10095
$\mathbf{x}_{232}^{\prime\prime 21}$	9541
$\mathbf{x}_{132}^{\prime\prime 22}$	273
$\mathbf{x}_{232}^{\prime\prime 22}$	200

Table 35: Continued.

$\mathbf{x}_{132}^{\prime\prime 23}$	107
$\mathbf{x}_{232}^{\prime\prime 23}$	150
$\mathbf{x}_{131}^{\prime\prime 31}$	15443
$\mathbf{x}_{231}^{\prime\prime 31}$	13527
$\mathbf{x}_{131}^{\prime\prime 32}$	660
$\mathbf{x}_{231}^{\prime\prime 32}$	590
$\mathbf{x}_{131}^{\prime\prime 33}$	84
$\mathbf{x}_{231}^{\prime\prime 33}$	105
$\mathbf{x}_{132}^{\prime\prime 31}$	9147
$\mathbf{x}_{232}^{\prime\prime 31}$	8441
$\mathbf{x}_{132}^{\prime\prime 32}$	245
$\mathbf{x}_{232}^{\prime\prime 32}$	220
$\mathbf{x}_{132}^{\prime\prime 33}$	80
$\mathbf{x}_{232}^{\prime\prime 33}$	80
$\mathbf{x}_{141}^{\prime\prime 11}$	7469
$\mathbf{x}_{241}^{\prime\prime 11}$	2866
$\mathbf{x}_{141}^{\prime\prime 12}$	354
$\mathbf{x}_{241}^{\prime\prime 12}$	350
$\mathbf{x}_{141}^{\prime\prime 13}$	74
$\mathbf{x}_{241}^{\prime\prime 13}$	82
$\mathbf{x}_{142}^{\prime\prime 11}$	316
$\mathbf{x}_{242}^{\prime\prime 11}$	8830
$\mathbf{x}_{142}^{\prime\prime 12}$	147
$\mathbf{x}_{242}^{\prime\prime 12}$	145
$\mathbf{x}_{142}^{\prime\prime 13}$	28
$\mathbf{x}_{242}^{\prime\prime 13}$	30
$\mathbf{x}_{141}^{\prime\prime 21}$	1298
$\mathbf{x}_{241}^{\prime\prime 21}$	9756
$\mathbf{x}_{141}^{\prime\prime 22}$	484
$\mathbf{x}_{241}^{\prime\prime 22}$	624
$\mathbf{x}_{141}^{\prime\prime 23}$	136
$\mathbf{x}_{241}^{\prime\prime 23}$	181
$\mathbf{x}_{141}^{\prime\prime 21}$	7571
$\mathbf{x}_{242}^{\prime\prime 21}$	7462
$\mathbf{x}_{142}^{\prime\prime 22}$	223
$\mathbf{x}_{242}^{\prime\prime 22}$	296
$\mathbf{x}_{142}^{\prime\prime 23}$	128
$\mathbf{x}_{242}^{\prime\prime 23}$	85
$\mathbf{x}_{141}^{\prime\prime 31}$	19304
$\mathbf{x}_{241}^{\prime\prime 31}$	18452
$\mathbf{x}_{141}^{\prime\prime 32}$	574
$\mathbf{x}_{241}^{\prime\prime 32}$	644
$\mathbf{x}_{141}^{\prime\prime 33}$	73
$\mathbf{x}_{241}^{\prime\prime 33}$	73
$\mathbf{x}_{142}^{\prime\prime 31}$	8315
$\mathbf{x}_{242}^{\prime\prime 31}$	7641
$\mathbf{x}_{141}^{\prime\prime 32}$	223
$\mathbf{x}_{242}^{\prime\prime 32}$	248
$\mathbf{x}_{142}^{\prime\prime 33}$	88
$\mathbf{x}_{242}^{\prime\prime 33}$	120

Table 36: Values of the decision variable $x_{j'kr}^{'''po}$.

$\mathbf{x}_{111}^{'''11}$	30708
$\mathbf{x}_{111}^{'''12}$	1325
$\mathbf{x}_{111}^{'''13}$	71
$\mathbf{x}_{112}^{'''11}$	42792
$\mathbf{x}_{112}^{'''12}$	1681
$\mathbf{x}_{112}^{'''13}$	40
$\mathbf{x}_{111}^{'''21}$	36748
$\mathbf{x}_{111}^{'''22}$	1279
$\mathbf{x}_{111}^{'''23}$	496
$\mathbf{x}_{112}^{'''21}$	35957
$\mathbf{x}_{112}^{'''22}$	1128
$\mathbf{x}_{112}^{'''23}$	468
$\mathbf{x}_{111}^{'''31}$	70159
$\mathbf{x}_{111}^{'''32}$	1486
$\mathbf{x}_{111}^{'''33}$	544
$\mathbf{x}_{112}^{'''31}$	47231
$\mathbf{x}_{112}^{'''32}$	1063
$\mathbf{x}_{112}^{'''33}$	308
$\mathbf{x}_{121}^{'''11}$	11810
$\mathbf{x}_{121}^{'''12}$	911
$\mathbf{x}_{121}^{'''13}$	80
$\mathbf{x}_{122}^{'''11}$	24005
$\mathbf{x}_{122}^{'''12}$	1034
$\mathbf{x}_{122}^{'''13}$	35
$\mathbf{x}_{121}^{'''21}$	26079
$\mathbf{x}_{121}^{'''22}$	1624
$\mathbf{x}_{121}^{'''23}$	549
$\mathbf{x}_{122}^{'''21}$	28252
$\mathbf{x}_{122}^{'''22}$	1624
$\mathbf{x}_{122}^{'''23}$	423
$\mathbf{x}_{121}^{'''31}$	50427
$\mathbf{x}_{121}^{'''32}$	1783
$\mathbf{x}_{121}^{'''33}$	391
$\mathbf{x}_{122}^{'''31}$	28948
$\mathbf{x}_{122}^{'''32}$	1519
$\mathbf{x}_{122}^{'''33}$	359
$\mathbf{x}_{131}^{'''11}$	19684
$\mathbf{x}_{131}^{'''12}$	1035
$\mathbf{x}_{131}^{'''13}$	60
$\mathbf{x}_{132}^{'''11}$	24005
$\mathbf{x}_{132}^{'''12}$	991
$\mathbf{x}_{132}^{'''13}$	34
$\mathbf{x}_{131}^{'''21}$	33191
$\mathbf{x}_{131}^{'''22}$	1798
$\mathbf{x}_{131}^{'''23}$	390
$\mathbf{x}_{132}^{'''21}$	39810
$\mathbf{x}_{132}^{'''22}$	1798
$\mathbf{x}_{132}^{'''23}$	332
$\mathbf{x}_{131}^{'''31}$	5481
$\mathbf{x}_{131}^{'''32}$	1486
$\mathbf{x}_{131}^{'''33}$	340
$\mathbf{x}_{132}^{'''31}$	33519

Table 36: Continued.

$\mathbf{x}_{132}^{'''32}$	1013
$\mathbf{x}_{132}^{'''33}$	372
$\mathbf{x}_{141}^{'''11}$	16535
$\mathbf{x}_{141}^{'''12}$	869
$\mathbf{x}_{141}^{'''13}$	74
$\mathbf{x}_{142}^{'''11}$	13568
$\mathbf{x}_{142}^{'''12}$	603
$\mathbf{x}_{142}^{'''13}$	28
$\mathbf{x}_{141}^{'''21}$	22522
$\mathbf{x}_{141}^{'''22}$	1102
$\mathbf{x}_{141}^{'''23}$	337
$\mathbf{x}_{142}^{'''21}$	24399
$\mathbf{x}_{142}^{'''22}$	1102
$\mathbf{x}_{142}^{'''23}$	287
$\mathbf{x}_{141}^{'''31}$	43849
$\mathbf{x}_{141}^{'''32}$	1188
$\mathbf{x}_{141}^{'''33}$	425
$\mathbf{x}_{142}^{'''31}$	42661
$\mathbf{x}_{142}^{'''32}$	861
$\mathbf{x}_{142}^{'''33}$	243

Table 37: Changes in each objective function per 50 iterations.

Iteration	Changes in the first objective function (percentage)	Changes in the second objective function (normalized between 0 and 1)	Changes in the third objective function (Toman)
50	7.99	0.90873	467500000
100	7.8	0.70214	451000000
150	6.8	0.45398	438000000
200	6.4	0.35193	398400000
250	5.5	0.26031	375000000

observed, during the implementation of the algorithm, 1 to 250 iterations have been determined, and the algorithm has shown an upward trend with regards to accuracy. Also, at roughly the 200th iteration, the algorithm achieves 90% convergence, with no changes in the responses from that point forward. This shows that the algorithm performance is highly accurate; therefore, the findings from the implementation of this algorithm can be trusted to solve the supply chain problem being analyzed.

Figure 3 illustrates the results from the effects of the algorithm implementation on the first objective, that is, the minimization of the unresponded demands. It can be seen that the range of the changes in each iteration of the algorithm, up to the maximum iteration, is [5.5-8.5]. With an increase in the iteration, the unresponded demand converges at approximately 0.5.

Figure 4 illustrates the results from the effects of the algorithm implementation on the second objective of the

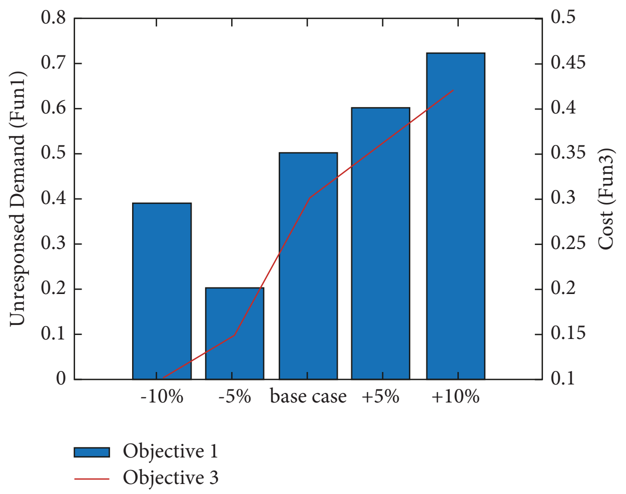

FIGURE 10: Sensitivity analysis of parameter $w_k^{''p}$ and its impacts on the first and third objective functions.

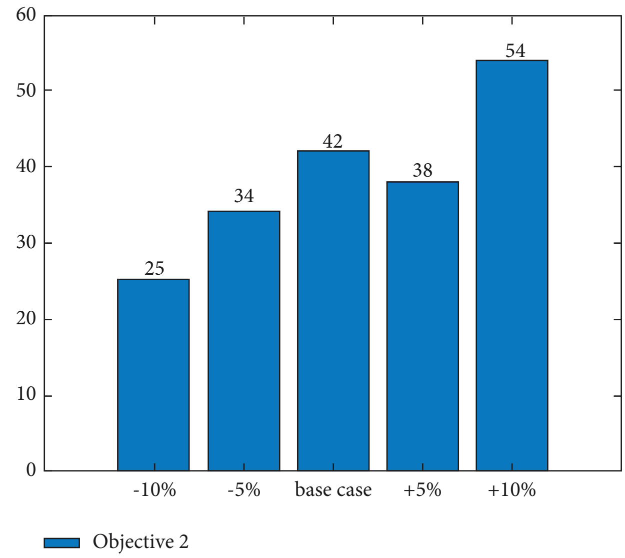

FIGURE 11: Sensitivity analysis of parameter δ_k^p and its impacts on the second objective function.

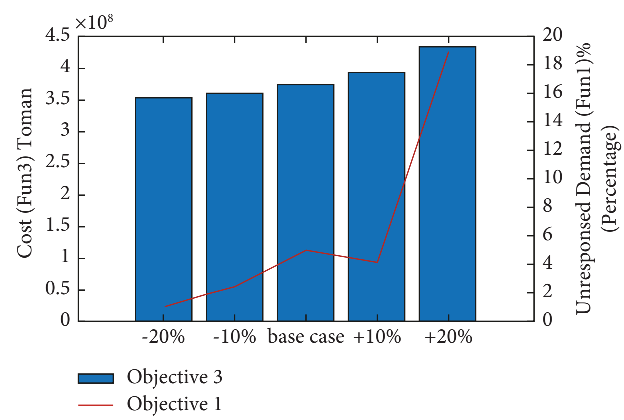

FIGURE 12: Sensitivity analysis of parameter $D_k^{''p}$ and its impacts on the first and third objective functions.

model, that is, the minimization of destructive environmental effects. It can be seen that the range of the changes in each iteration of the algorithm, up to the maximum iteration, is [0.1-0.8]. With an increase in the iteration, the destructive environmental effects converge at approximately 0.1.

Figure 5 illustrates the results from the effects of the algorithm implementation on the second objective of the model, that is, the minimization of destructive environmental effects. It can be seen that the range of the changes in each iteration of the algorithm, up to the maximum iteration, is [0.2-1]. During an increase in the iteration, the cost converges at approximately 0.2.

Given that the designed relief supply chain in this study is multiobjective, we need to extract the Pareto archive from the algorithm for the comparison of one objective with other objectives. The Pareto archive shows whether the algorithm sought to achieve optimal responses or not. Considering the objective functions introduced in the humanitarian supply chain model in this study, Figure 6 illustrates the Pareto archive of each objective.

Figure 6 is a 3D depiction of the Pareto archive of the responses obtained during each iteration of the algorithm for every three objectives. According to the graph, the algorithm has clearly attempted to reduce the unresponded demands, the destructive environmental effects, and the costs to solve the problem. Further, the problem has been solved in a way to minimize each of the objectives during each iteration. The majority of the responses have been compressed near the minimum ranges of each three objectives, and the dispersion of the responses is marginal. The results reveal that, ultimately, the responses for the unresponded demands have converged at roughly 5%, for the destructive environmental effects at 10%, and for the costs at 20%. Figures 7-9 show separate 2D graphs of the Pareto archive of the objective functions.

Findings obtained from numerous experiments revealed that the weights of the first objective are greater than the other two objectives with the first objective weighing 0.5 ($\alpha 1 = 0.5$), the second 0.2 ($\alpha 1 = 0.2$), and the third 0.3 ($\alpha 1 = 0.3$). Also, the values of the decision variables are shown in Tables 33-36, and the changes in each objective function per 50 iterations are shown in Table 37.

7. Sensitivity Analysis

To examine the effect of parameter $w_k^{''p}$ on the first and third objective functions, we solved the problem with different values (+10%, +5%, ground state, −5%, and −10%) and reported the behavior of the first and third objective functions. According to Figure 10, a 5% increase in the parameter does not have a significant impact on the first objective function. However, a decrease by the same amount would reduce in first objective function by 30%. Further, a 10% increase/decrease in the parameter on the third objective function is substantial.

Figure 11 shows that a 5% decrease/increase in parameter δ_k^o does not cause a significant change in the second objective function. However, a 10% decrease/increase in the coefficient of the parameter would decrease and increase the second objective function by 17% and 12%, respectively.

Figure 12 shows the sensitivity analysis of parameter $D_k^{''p}$ on the first and third objective functions. The increase/decrease in the perimeter on the third objective function in the considered scope is not substantial, whereas, for instance, a 20% increase in the parameter on the first objective function is.

8. Conclusions and Outlook

In this research, an attempt was made to provide a design by observing the dimensions of the sustainability in the humanitarian supply chain model in the face of the crisis, in a local way according to the policies of the country of Iran. Considering the research gap, this study introduced a relief supply chain model under uncertainty with a leader-member exchange approach. Accordingly, on the upper level, the government, as the supplier, would provide distributors (governmental and nongovernmental) with relief goods so that they could distribute them to victims at demand points. Afterward, the model was solved using MOEA/D. According to the results, the selected algorithm has high accuracy and acceptable performance. Further, during each iteration, the objective functions became more optimized. It was also revealed that the objective function associated with the minimization of the unresponded demands outweighed the other objectives. Finally, the sensitivity of the objective functions to several parameters was examined. In the future research, we intend to locate distribution organizations based on appropriate criteria and also apply government budget restrictions and use simulation methods to extract better results.

Data Availability

There are no available data for this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Operation of European Football Supply Chain in China Based on Meta-Analysis

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Football is a sport in which two teams play offense and defense against each other on the same rectangular court according to certain rules. As a key project in China's professional and commercial development, football supply chain has its own mode of operation. In order to compare and study the operation of European football supply chain in China, in this paper, we conduct a study on the operation of European football supply chain in China through principal component analysis to establish a model suitable for the operation of Chinese football supply chain. It is concluded that through research under the existing model, we should establish and improve the system, change the supply chain management mechanism, establish and improve the operation mechanism, clearly establish the ownership of the supply chain, and clear the rights and responsibilities. In addition, we also adopt an independent operation mechanism in line with the market and a self-financing business operation model.

1. Introduction

As the world's number one sport, football occupies an important geographical position in the global competition. A country's performance in football reflects the country's comprehensive strength, international political and economic status, and influence, which cannot be ignored [1].

Their football supply chain league operation mode is very characteristic, has been gradually accumulated in the decades of business operation, and has a set of perfect league operation mode. As of the 2018/19 season, the top five football leagues (La Liga, France's Ligue 1, Premier League, Italy's Serie A, and Germany's Bundesliga) account for 75% of all European league revenues. Football is the number one sport in the world. However, football is still a brand new thing in China. According to the analysis of the existing data, the operation of Chinese supply chain is still in an exploratory period.

The European football league is to improve the appeal of the game, market-oriented development as far as possible to meet the needs of consumers, and profit as the ultimate goal of its marketization development. Due to the late start of Chinese supply chain, their operation mode is still in the exploratory period. This article uses the method of documentary, comparison, and analysis to Chinese football supply chain league operation with mature operation and commercial operation is a comparative study of successful European football supply chain, in order to seek a new way of thinking for the operation of the Chinese football league supply chain, promote the establishment of suitable for China's soccer league operation mode, Accelerate the process of professionalization and commercialization of Chinese football supply chain league.

2. Comparison of Operation Objectives of European Football Supply Chain Leagues in China

In order to achieve better performance and improve China's football level, the Chinese Football League has carried out a clear operation target positioning. The significance of a business plan is that it is the outline and guide of other plans of the enterprise. It is characterized by decision making. Based on the premise that enterprises are relatively independent commodity producers and operators, it is formulated and compiled according to the external environment of enterprises and their own capabilities.

The purpose of the constitution of China's Football Association is abide by the constitution, laws, regulations, and national policies of the People's Republic of China, observe social morality, abide by the statutes of the International Football Federation and the Asian Football Federation, unite football workers in China, extensively develop football, and vigorously develop football. To enhance the people's physical fitness, enrich the people's amateur cultural life, improve the level of football, and strengthen the construction of social spiritual civilization, strengthen the contact and exchange among the members of the association, and strive to improve the management system and operation mechanism of Chinese football, To promote the improvement of the management level of member associations, professional supply chain and other football organizations, to take an active part in the official matches and activities of the International Football Federation and the Asian Football Federation, to promote international exchanges, and to enhance the friendship between football associations, supply chains and players in various countries and regions.

In 2016, China issued a report entitled "Medium and Long-Term Development Plan for Chinese Football (2016–2050)," which divided the development of Chinese football into three stages. In terms of development goals, the plan will be divided into three stages: short-term goals (2016–2020)—strive to achieve the development goals of maintaining the basic, strengthening the grassroots and laying the foundation of Chinese football; Mid-term goal (2021–2030) strive to achieve the development goal of Chinese football with more power, more vitality and more influence, and to be among the world's leading teams; Long-term goal (2031–2050) To fully realize the goal of being a first-class football power, realize the all-round development of Chinese football, realize the football dream of the Chinese people, and make due contribution to the world football sport.

Its main goal is to ensure the basic, strong grassroots and lay the foundation of Chinese football. Ensure basic: basically meet the needs of the people in football, so that the needs of the people to carry out football venues, time and so on can be met, and form a good football atmosphere. Strong grassroots: strengthen the construction of campus football. Lay the foundation: initially establish the football management system and mechanism with Chinese characteristics, create the framework of policies and regulations, build reasonable competition and training system, and basically form the coordinated development of football cause and industry [2].

It can be seen from the above articles of association and the documents of the long-term plan of Chinese football that the primary goal of the development of Chinese Football League is to fully realize the goal of becoming a first-class football power, to realize the all-round development of Chinese football, to realize the football dream of the Chinese people, and to make due contributions to the world football.

Capitalist countries experienced hundreds of years of blood and tears, slowly forming a relatively perfect market economic system structure and production means of private ownership of the formation of the European professional supply chain and European football leagues [3]. The state of nature is an economic phenomenon generated by demand. Their operation mode, mechanism, and system evolved in the process of the continued survival of the fittest in the market economy, but they do not form interference factors in the process. As their real economy, they want to give Europe a positive, watchable, and valuable "product." The outcome of football matches is unpredictable because of factors beyond your control. Because the outcome of the competition is so uncontrollable, it attracts the European people to become obsessed with it. Therefore, European football league to improve the appeal of the game, market-oriented development, as far as possible to meet the needs of consumers, so profit as the ultimate goal of its market-oriented development.

To sum up, the development goal of China's football league is to fully realize the goal of becoming a first-class football power, realize the all-around development of Chinese football, realize the football dream of the Chinese people, and make contributions to world football. European football league is to improve the appeal of the game, market-oriented development, as far as possible to meet the needs of consumers, profit as the ultimate goal of its marketization development.

3. Comparison of Operation System Changes of European Football Supply Chain Leagues in China

Human beings as actors are purposeful. Institutions are intended or unintended consequences of purposeful behavior. From the root point of view, institutions can also be divided into two types, one is the internal system, and the other is the external system, so we can divide institutional change into two types, which are temptation leading type and compulsion type, respectively [4]. Induced institutional change refers to the spontaneous changes made by a group of people in response to profit opportunities caused by institutional imbalances; mandatory institutional changes refer to changes caused by government decrees. Although spontaneous institutional change usually requires government action to promote it, for the sake of analysis, this paper distinguishes these two types of change.

Compared with Europe, China's sports industry has a late start and is not perfect in many aspects. There is a lot of space for exploration [5]. The professional football system in China started entirely with government-mandated supply, and the model of this system was established from top to bottom.

The natural evolution of market demand and system fails to become the main path of change. Producers of professional sports products in China depend on the government, not the market. The system is provided to supply chain alliances and supply chain organizations to obtain profits from producing relevant new products. The change of China's professional sports system is carried out within the scope of social environment, including political, economic, legal, and cultural level. It can be seen from the above that the arrangement of the producers of professional sports products depends on the government rather than the market, which makes the institutional change caused by demand not become a closed cycle path, but a change path of a non-market orientation composed of the government and consumers.

The operation mode of sports organizations in European countries is formed from bottom to top, which has experienced many years of institutional reform and the various games with its interests. Its system has a high degree of running-in with its national legal system and economic system. The system of its football league changes from bottom to top.

Eurosport's model of operation is determined by the market, not by governments. Is what the market needs to support the product and the direction of the market needs to develop, to the market system for perfect.

To sum up, the change of China's sports organization operation system is started by the government's compulsory supply, which is implemented from the central to the local and established from top to bottom or can be said to be promoted by the government. The Chinese government is in full control of the perfection and exploration of sports organization system. In Europe, the European government has only macro-regulation.

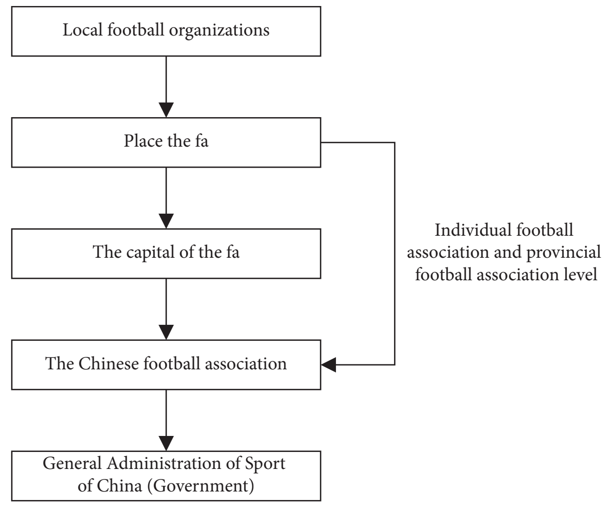

Figure 1: Organization structure chart of Chinese football.

Table 1: Ticket and commodity sales revenue of Guangzhou football supply chain (ten thousand yuan).

Project	Ticket revenue	Revenue from commodity sales
2014	5453.9	2383.9
2015	21023.9	2505.5
2016	4772.2	1042
2017	4783.3	1238.61
2018	4123.1	2400.17
2019	5520.42	2936.85

Data source: according to the annual report of Guangzhou football supply chain.

4. Comparison of Organization, Nature, and Management Characteristics of European Football Supply Chain Leagues in China

4.1. China. At present, the operation of the Chinese Football League is managed by the local football associations, which are managed by the provincial football associations (except for some local football associations which are at the same level as the provincial football associations, such as Nanjing Football Association and Jiangsu Football Association). The provincial football associations are directly managed by the Chinese Football Association. The Chinese Football Association supervises and administers football affairs at the national level as authorized by law and entrusted by the government (see Figure 1 for the relationship between China's football organizations).

The Chinese Football Association (hereinafter referred to as the Chinese Football Association) is an organization engaged in football in China and is a national non-profit sports association legal person of its own free will. The nature of the non-profit community groups, but its leaders are appointed by the state general administration of sports and appointed, 2016 football sports management center (the original subordinate units of the General Administration of Sport of China) revoked, the original football management center of functional responsibilities are classified in China football association, the Chinese Football Association to the identity of the corporation to supervision and management of the affairs of the national football, It is similar to administrative organs and public institutions, and under the direct leadership of the General Administration of Sport of China, which belongs to the relationship between superiors and subordinates. Therefore, the Chinese Football Association has an administrative level.

At present, Tian He Stadium, the home stadium of Guangzhou football supply chain, has an average audience of more than 40,000 per game from 2014 to 2019, which is the largest among all the supply chains in the Chinese Super League. The number of fans on Tie Ba and Weibo has been 4.683 million and 7.97 million, ranking the top of the Chinese Super League [8–10]. All kinds of data show that Guangzhou Evergrande has the largest number of fans in the Chinese Super League, which lays a good economic foundation for the establishment of the fan trust, as shown in Table 1.

Because the football league organization is a non-membership organization, it belongs to the non-professional league. Between football association and supply chain is more rely on administrative means to restrain and manage. In the operation of football league, football association may not be able to fully stand on the interests of the operation like professional league, thus affecting the market benefits of football league to a great extent.

4.2. Europe. At present, after a long time of exploration, European supply chain's operation mode is gradually

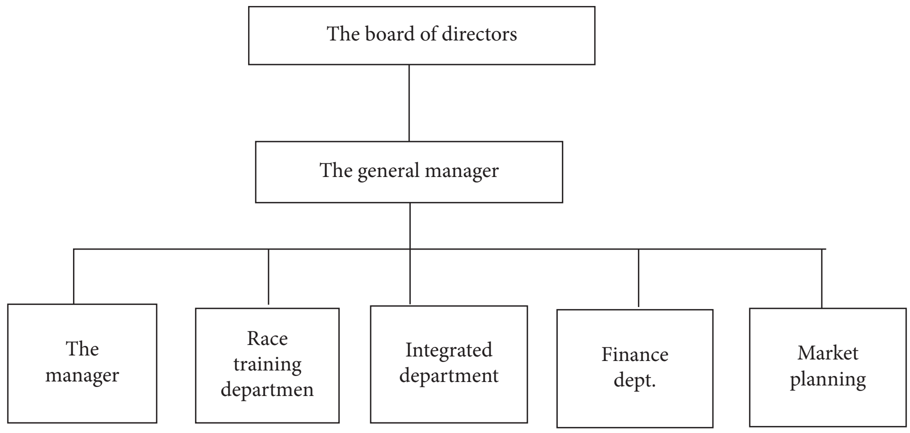

Figure 2: Schematic diagram of organizational structure of Chinese football clubs.

professionalized and commercialized. Its main funding comes from sponsors. As of 2018, Manchester United has a sponsorship fund of 279 million euros, with 68 sponsors, including shirt sponsor Adidas (85 million euros) and giant sponsor Chevrolet (53 million euros). However, the development of specialization and commercialization can ensure that the players have food, clothing, and shelter, so that they can devote themselves to the work of football. This greatly increases the motivation of the players.

Similar to China, Europe is also a corporate organization, but it is a for-profit corporate organization. As its football association, it belongs to its European countries such as the United Nations for Sport, He has the right of autonomy in dealing with affairs in the football organization and has certain authority in the football supply chain.

Union of European Football Associations (UEFA) usually makes decisions on major issues by voting with full consideration of the reality and the interests of all members. Its use of such a method has many characteristics: transparent management, fair and democratic, benefit sharing, and risk sharing, forming a business as a whole [6].

We find that Chinese football organizations operate under the direct management of associations, while European organizations operate under the simultaneous management of associations, leagues, and supply chains. This shows that the European organization structure fully considers the rights and interests of each member, so that everyone can participate in major decisions, forming a strong business whole [11–13]. Chinese football organizations operate under the direct management of associations, while European organizations operate under the simultaneous management of associations, leagues, and supply chains. Chinese football is more directly managed by the government, while in Europe, it is more dependent on supply chain sponsorship incentive mechanism, which affects its market efficiency.

5. Comparison of Organizational Functions of European Football Supply Chain in China

5.1. China. At present, the best corporate management examples of Chinese supply chain are Beijing Guoan and Shanghai SIPG, whose management is "secondary management." The plan passed by the chairman of the board of directors of the supply chain is implemented, while the head coach of the team is implemented under the leadership of the general manager. The general manager is elected by the board of directors, and its detailed organizational structure is shown in Figure 2.

Most supply chains in China are jointly handled by the board of directors and the football association. Coaches, athletes and the site is provided by the local football association, the supply chain has not unified organization structure model, because he will only according to their own development needs professional departments and establish what department, even most of the staff is in a state of part-time job, this may be a limit for the supply chain itself development. As a result, there are no important and indispensable professional divisions in their supply chains.

5.2. Europe. European supply chains are divided into private, corporate, and joint-stock operations. They have a clear organizational structure and division of responsibilities. The board of directors of the supply chain is composed of the investors of the supply chain, and its organizational structure is shown in Figure 3.

European supply chains are usually independent, and their advantage is to be flexible and to improve themselves according to market needs. In the process of operation, it is responsible for its own profits and losses and pays certain taxes to the state according to the laws of the country. The supply chain defines the rights and obligations of both parties by looking for coaches and players suitable for their development and signing contracts with them. The board of directors of the supply chain is established by the investors, so when making important decisions, they will elect the right choice which is best for the development of their supply chain according to their own development.

The cooperation between different departments makes the supply chain form a corporate operation mode, and it will adjust the departments it needs according to its own development and gradually explore and improve in the process of development.

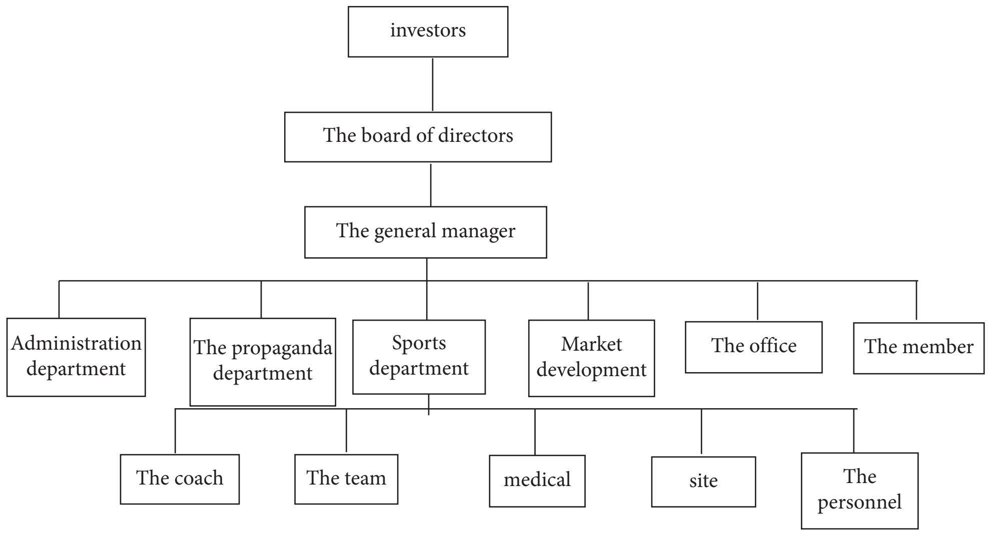

Figure 3: Schematic diagram of organizational structure of European football clubs.

To sum up, the Chinese football supply chain was not unified organization pattern, just according to their own needs what profession department set up the professional division, however, a lot of important professional department is the supply chain is of vital importance to the development of the department, propaganda department, market development department, for example, these departments are all played a role. However, the various organizations of European supply chains are relatively sound, and they will add more professional departments according to their own development needs, and their responsibilities and functions are very clear.

5.3. Comparison of Property Rights Relations between Chinese and European Supply Chains. Modern enterprise system as a "clear property rights, well-defined right and responsibility, the government, separate, management science," to establish modern enterprise system of shareholding system for the development of Chinese football supply chain goal, and our country most of the supply chain for the local association and enterprise joint, a few enterprises wholly for, although the joint handle may well play their respective advantages, resource conservation. However, there is no way to screen intangible assets such as coaches and team members invested by the sports bureau. As a result, local associations and enterprises jointly manage the property rights and responsibilities, and there is a lack of internal constraints and supervision system. When the supply chain benefits sharing, debt sharing, because of the property rights, responsibility is not clear, will affect the normal operation of the supply chain.

European football technology famous mo belongs to Spain, spread of such a word, imitate the Spanish football is not much, but, imitate the Spanish football is very knowledgeable people, which shows the Spanish football technology of the place. In Spain, the sports law gives professional supply chains the status of "sports corporation." German professional supply chains call it a "commercial sports enterprise." As early as 1968, Italy reformed its football organization and changed all professional supply chain into football companies. In Asia, Japan and South Korea lure athletes to companies with strong financial backing to keep them motivated [7].

To sum up, the property rights of professional supply chain in China have great problems. The division of property rights and responsibilities is unclear, and the internal mechanism lacks constraints and supervision mechanism. However, the European supply chain operates in the form of an enterprise, which is in line with the modern property rights system. The board of directors is jointly recommended and funded by the supply chain, and then the board of directors hires the general manager to operate the supply chain. The property rights of the supply chain are clear, and the supply chain has a sound restriction and supervision mechanism.

5.4. Discussion. It can be seen from the previous data that the Chinese football supply chain is an amateur league, and it will not stand in the interests of the supply chain management. Mechanism from the current China's football league operation objectives can be seen that the Chinese football market economy has not fully established, the administrative mechanism and market mechanism is mainly due to the intervention, resulting in the direction of the supply chain operations cannot according to their need for development, all kinds of public ownership of property has led to some supply chains with deep pockets to buy strong players. As a result, Chinese supply chain cannot develop in a balanced way, and a good competition mechanism cannot be formed. As a result, the polarization between the two levels is very serious, which makes Chinese Super League unstable.

In their eyes, sports industry is a huge industry, and its profit value is precious in their eyes. The incentive mechanism of staff at the supply chain and only pay attention to the individual employees, thus ignore the interests of the entire supply chain, resulting in the supply chain there is a one-way from top and bottom of administrative constraints, this kind of restraint has great disadvantages, rather than mutual restriction, mutual supervision of management. Foreign supply chain from capitalism in the state of the union, has a relatively perfect mechanism, also has a mature governance structure, the supply chain mainly adopts financial self-sufficiency, independent, self-management, a management mode, because when the supply chain need what mechanism to adapt to the development, there will be pressure to produce the supply chain to improve.

Because in its supply chain mechanism, profit is its primary goal. Therefore, the supply chain and the staff form an interdependent relationship, and the staff will devote themselves to the supply chain's corporate development. For a number of market reasons, the strength of each supply chain is balanced and promotes each other's development [16, 17]. They will maximize their own interests. They also seek to develop together, so that the supply chains make rules and supervise each other.

6. Conclusion

The constraint and supervision of Chinese supply chain are considered one-way constraint from top to bottom, rather than mutual constraint and supervision, while Europe mainly adopts a good mechanism of self-financing, independence, and self-development, and each supply chain can better regulate and restrain each other. Based on the comprehensive analysis of six aspects of the operation of football supply chain leagues in China and Europe, we have the following suggestions for Chinese supply chain to achieve professional and commercial development:

(1) Establish development goals corresponding to its own development.

(2) Improve the management system of the supply chain.

(3) Establish a more sound organizational structure to make the property rights and responsibilities of the supply chain clear.

(4) Operate in accordance with the market operation mechanism by being independent and responsible for profits and losses.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Research Article

Research on the Coordination of Fresh Food Supply Chain Based on the Perspective of Blockchain and Low Carbon

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We consider a three-stage fresh agricultural product supply chain consisting of a supplier, a third-party logistics service provider (TPLSP), and a retailer and discuss the coordination mechanism of "revenue sharing + double cost sharing" contracts and "two-part tariff + revenue sharing + double cost sharing" contracts between the supplier, TPLSP, and the retailer. Based on this, we not only explore the conditions for supply chain full coordination and Pareto improvement but also analyze the effect of blockchain technology application cost, consumer environmental protection awareness, freshness preference, green trust level on carbon emission reduction level, fresh-keeping effort level, price decisions, and profits by comparing three different decision-making models. Results show that the improvement of the green trust level can help to improve the carbon emission reduction level, fresh-keeping effort level, price decisions, and profits. The application of blockchain technology can reduce transaction costs and improve consumer green trust levels, thereby increasing market demand and profits. When environmental protection awareness and freshness preference are higher than a certain value, the unit retail price of fresh products under decentralized decision-making is the highest with the blockchain technology applied. TPLSP can increase the wholesale, service, and retail prices of fresh products by appropriately increasing the blockchain technology application cost-sharing ratio. When $15 < T_1 < 29.2416$ and $47 < T_2 < 66.0408$, "two-part tariff + revenue sharing + double cost sharing" contracts can achieve the Pareto improvement.

1. Introduction

In January 2020, the Ministry of Agriculture of China issued the "Digital Agriculture and Rural Development Plan" which pointed out that the innovative application of blockchain technology in quality, safety traceability, and supply chain information transparency should be developed. In September 2020, the Chinese government put forward at the United Nations General Assembly: "China strives to achieve carbon peaking by 2030 and carbon neutrality by 2060." Based on these policies, in November 2021, the State Council of China promulgated ""The 14th Five-Year" Cold Chain Logistics Development Plan" pointed out that the development of cold chain logistics can expand the supply in high-quality markets and meet different consumption needs of the people. It is an important guarantee for improving the quality and safety system of fresh agricultural products and building a healthy China. It is also proposed to speed up the application of blockchain technology in the construction of cold chain logistics intelligent monitoring and traceability system to improve the authenticity, timeliness, and credibility of traceability information. At the same time, since cold chain logistics warehousing, transportation, and other links require quite a lot of energy consumption, achieving carbon peak and carbon neutrality puts forward some new requirements for the low-carbon development of cold chain logistics, thus encouraging the application of green, safe, energy-saving, and environmentally friendly refrigerated trucks as well as the use of high-efficiency, low-carbon refrigeration agents, and insulation materials.

Fresh agricultural products are indispensable commodities in people's daily life. They have the characteristics of seasonal supply and are easy to deteriorate, which may cause great losses in the process of logistics [1, 2]. According to the statistics, the annual loss rate of fresh agricultural products in China ranges from 25% to 35% [3]. Therefore, fresh agricultural products need precise control over the temperature and humidity during transportation and storage. Under this demand, many third-party logistics providers (TPLSPs) with cold chain technology have emerged, and the three-tier supply chain composed of suppliers, TPLSPs, and retailers have become one of the main logistics modes for fresh products. With the intensification of international competition and the popularization of the concept of low-carbon environmental protection, the “carbon label” has become an important factor affecting the export of fresh products in China [4]. Therefore, TPLSPs should reduce carbon emissions as much as they could in the process of low-temperature storage and cold chain transportation of fresh agricultural products.

In addition, in recent years, consumers’ awareness of environmental protection has gradually increased, resulting in their will to pay higher prices for high-quality fresh products. The carbon emission reduction level in the logistics process and the freshness of fresh products have become the decisive indicators for consumers’ choices. As supply chain companies may have problems such as information fraud and false reporting, consumers cannot have absolute green trust in them, thus affecting the demand for fresh products. As an immutable, open, and transparent database, blockchain technology plays a positive role in the green operation of the fresh agricultural product supply chain [5]. The application of blockchain technology by enterprises enables consumers to understand products’ real information and effectively solve the green trust problem of consumers when purchasing fresh products [6, 7], when the “smart contract technology” in the blockchain enables enterprises to strengthen the level of collaborative operation, improve operational efficiency, and reduce transaction costs [8, 9]. Therefore, it is of great significance to study the coordination of fresh agricultural product supply chains from the perspective of blockchain and low-carbon.

We tend to study the following questions:

(1) In the tertiary fresh agricultural product supply chain, what is the impact of consumers’ green trust level, environmental protection awareness, freshness preference, and application cost of blockchain technology on the decision-making and profits of the supply chain system?

(2) Does the application of blockchain technology have a positive impact on the supply chain system? Are the decisions and profits of each enterprise in the supply chain under the centralized decision-making model better than the optimal results under the decentralized decision-making model?

(3) How to design an effective contract incentive mechanism to improve the operation efficiency of the supply chain in order to increase the participants’ profits in the supply chain?

In order to answer the questions mentioned above, this paper constructs a three-stage fresh agricultural product supply chain dominated by a TPLSP, followed by a supplier and a retailer, with contractual coordination among the three parties. We first compare the decision-making and profits of the fresh agricultural product supply chain system without the application of blockchain technology under decentralized decision-making and when blockchain technology is applied. For the situation where the benefits are higher, we analyze the supply chain participants’ decisions and profits in the centralized decision-making mode. Then, we introduce the contract incentive mechanism to explore the conditions of sufficient coordination and Pareto improvement areas to maximize the profits of the supply chain system or achieve a triple-win situation. Finally, we verify the impact of various factors and coordination contracts on the decision-making and profits of the supply chain system through numerical example simulation analysis.

In conclusion, the present study contributes to the literature from the following two aspects:

(1) This paper comprehensively considers that the fresh agricultural products demand is affected by the retail price, carbon emission reduction level, fresh-keeping effort level, consumer freshness preference, environmental protection awareness, and green trust level, studies the decision-making issues of supply chain pricing, fresh-keeping, and carbon emission reduction, and expands the research scope of factors affecting the supply chain of fresh agricultural products and the theory of low-carbon supply chain operation and management

(2) This paper compares and analyzes the decision-making results of the fresh agricultural product supply chain before and when blockchain technology is applied and designs two combined contracts for coordination, which enriches the research direction of the fresh agricultural product supply chain decision-making, refines and enriches the supply chain coordination mechanism, and provides help for solving related practical problems

We organize the rest of this paper as follows. Section 2 reviews the relevant literature at home and abroad and puts forward the innovations of this paper. Section 3 shows the problem statement, constructs a three-level agricultural product supply chain model, compares and analyzes the optimal decision-making and profits of the supply chain system under different decision-making modes, and analyzes the feasibility and coordination conditions of the two contract incentive mechanisms. Section 4 verifies the previous analysis results through mathematical analysis and various numerical examples. Section 5 presents managerial insights and practical implications. Section 6 summarizes our findings and outlook. All the proof procedures in this paper are given in the appendix.

2. Literature Review

At present, related research can be summarized into three aspects: (1) research on the coordination of fresh agricultural product supply chain, (2) carbon emission reduction in the supply chain, and (3) applications of blockchain technology in the supply chain.

2.1. Research on the Coordination of Fresh Agricultural Product Supply Chain. So far, many researchers have studied the coordination of the fresh agricultural product supply chain. For example, Alinezhad et al. [10] analyzed a case study problem in the perishable product industry, and the results demonstrated the superiority of the Lp metric over goal-achieving methods. Tirkolaee and Aydin [11] optimized a sustainable multilevel multiproduct supply chain and combined transportation network for perishable product distribution by introducing a fuzzy two-level decision support system. The above-given literature proposes new methods to optimize the supply chain of fresh agricultural products. At the same time, coordination contracts have also become an effective way to improve the efficiency of supply chain profits and operational collaboration. Cachon [12] summarized several commonly used supply chain contract coordination mechanisms and concluded that for the fresh product cold supply chain, revenue-sharing contracts, cost-sharing contracts, and repurchase contracts are the most common coordination contracts. Hu and Feng [13] constructed a supply chain model with service demand under the situation of uncertain supply and demand, designed a revenue-sharing contract, and analyzed the optimal decision-making of buyers and suppliers along with the feasible conditions for coordinating supply chains.

The above-given literature only designs a single contract incentive mechanism to coordinate the supply chain, but subsequent research shows that the combined contract is more advantageous and applicable. For instance, Yan et al. [14] constructed a fresh agricultural product supply chain considering strategic consumer behavior and solved the problems in decentralized decision-making by designing two contract incentive mechanisms based on revenue sharing and wholesale price. The study of Pang et al. [15] found that revenue-sharing contract alone could not achieve perfect coordination of the three-stage supply chain consisting of one manufacturer, one distributor, and one retailer, but when combined with the constraints of rebate and penalty contracts, it can coordinate the supply chain well. Due to the advancement of cold chain technology, there have been many third-party logistics service providers (TPLSPs) that provide fresh food preservation and distribution services. Therefore, on the basis of the above-given literature, it is necessary to conduct a coordinated study on the fresh food supply chain in which TPLSP participates. Ma et al. [16] studied the decision-making and system profits of each member in the three-stage supply chain system which consists of farmers, third-party logistics providers (TPLPs), and retailers and designed a combination of "cost sharing + revenue sharing." This coordination mechanism makes every participant's profits in the supply chain achieve Pareto improvement. Although the above-given literature studies the coordination of the supply chain of fresh agricultural products, the research perspective and the setting of influencing factors are relatively simple. On this basis, this paper considers the supply chain coordination research from the perspective of low carbon and blockchain and analyzes the impact of consumer environmental protection awareness, freshness preference, and green trust level on decision-making and profits in the fresh agricultural product supply chain.

2.2. Carbon Emission Reduction in the Supply Chain. Nowadays, as people's low-carbon and environmental protection awareness increases, their preference for green products increases as well; when global warming puts forward new requirements for carbon emissions, the issue of carbon emission reduction in the supply chain has also become a research hotspot in academia [17, 18]. For example, Hu et al. [19] studied how companies make optimal carbon emission reduction decisions in a low-carbon environment. Dai and Wang [20] and Chai et al. [21] studied the influences of carbon emission constraints on supply chains in different market scenarios. Based on this, Das et al. [22] further studied the impact of carbon tax policy in the multiobjective green physical logistics model under sustainable development. The above-given literature considers carbon emission reduction in the supply chain [23, 24] but does not consider the particularity of the fresh agricultural product supply chain. Bai et al. [25] constructed a fresh food supply chain dominated by suppliers, followed by manufacturers and two retailers, in which they analyzed the impact of carbon policies on optimal decisions and profits. Mishra et al. [26] believed that price and inventory levels were the main factors affecting the demand for fresh products, they, therefore, constructed and analyzed an optimal inventory control model for fresh products.

It can be seen from the previous literature that most products generate carbon emissions during production and processing [27, 28], and the carbon emissions of fresh agricultural products are mainly generated by low-temperature storage and cold chain transportation to maintain freshness. Therefore, on this basis, this paper constructs a three-stage fresh agricultural product supply chain with TPLSP as the leading enterprise and then analyzes the main factors that affect TPLSP fresh-keeping, carbon emission reduction, and pricing decisions.

2.3. Applications of Blockchain Technology in the Supply Chain. In recent years, the application of blockchain technology in supply chain research has attracted the attention of many researchers [29]. Saberi et al. [30] found that blockchain technology can break the information barriers between supply chain enterprises and play a positive role in promoting the innovation of supply chain finance. Li et al. [31] designed a "blockchain + collaborative emission reduction" information sharing mechanism to improve the supply chain revenue, thus solving the problem of reduced efficiency of supply chain coordinated emission reduction caused by consumers' nondisclosure of low-carbon preferences. The above-given literature further considers the impact of the application of blockchain technology on the supply chain but does not consider the impact of blockchain technology on carbon emission reduction and the fresh agricultural product supply chain. In terms of carbon reduction, Manupati et al. [32] designed a distributed ledger-based blockchain approach to address various production distribution issues in multilevel supply chains under carbon tax policies. Zhang et al. [33] constructed a three-stage supply chain composed of the government, manufacturers, and retailers, then analyzed the supply chain's optimal carbon emission reduction rate, low-carbon product output, and social welfare application under four scenarios with or without the application of blockchain technology and two kinds of government subsidies. They also studied the optimal strategy of government low-carbon subsidies. In terms of the fresh agricultural product supply chain, Xu et al. [34] found that the application of blockchain technology by manufacturers can not only improve the greenness of products but also help optimize and coordinate supply chains. He et al. [35] studied the impact of blockchain technology on the pricing decisions and profits of participants in the global fresh agricultural product supply chain. Cui and Yao [36] constructed an evolutionary game model of an agricultural product supply chain using blockchain technology and discussed the key factors that affect participants' compliance with the rules of blockchain nodes. The above-given literature has studied the role of blockchain technology in the low-carbon supply chain and the supply chain of fresh agricultural products, respectively, but there is no literature that considers the impact of applying blockchain technology on the supply chain of low-carbon fresh agricultural products. Therefore, this paper will study this issue.

2.4. Research Gap. To sum up, most existing literature only consider the impact of a single or partial factors such as the retail price of fresh products, carbon emission reduction, or freshness on market demand and ignores the level of consumer green trust's effects on demand, prices, levels of carbon reduction, and fresh-keeping efforts [37, 38]. There are many studies on the application of blockchain technology in low-carbon supply chains or agricultural product supply chains, but few scholars have studied the three-stage fresh agricultural product supply chain from the perspective of blockchain and low-carbon, and there is also room for improvement in coordination contracts. Therefore, this paper considers the three-stage supply chain system dominated by TPLSP, followed by suppliers and retailers and studies the decision-making and coordination problems of this system under the application of blockchain technology.

As shown in Table 1, a comparison with previous literature shows that the innovations and advantages of this paper are as follows: first, this paper considers the comprehensive impact of the retail price, environmental protection awareness, freshness preference, and green trust level on the demand for fresh agricultural products. Second, this paper explores the impacts of the application of blockchain technology, carbon emission reduction and fresh-keeping cost coefficients, consumer behavior preferences and other factors on the level of preservation efforts, carbon emission reduction levels, pricing decisions, and the profits of each main body in the supply chain. Third, this paper compares the decision-making and profits of the three-stage fresh food supply chain system under decentralized decision-making with and without the application of blockchain technology, on which we base to provide theoretical support for the decision-making of suppliers, retailers, and TPLSP. Fourth, this paper compares the decision-making and benefits of the supply chain system under the decentralized and centralized decision-making mode when applying blockchain technology, before designing the contracts of "revenue sharing + double cost sharing," and "two-part tariff + revenue sharing + double cost sharing" incentive mechanism to achieve the perfect coordination of profits among the main bodies of the supply chain system.

Therefore, in a theoretical sense, based on low-carbon theory and blockchain technology theory, this paper expands the research scope of fresh agricultural product supply chain decision-making and refines and enriches the supply chain coordination mechanism by designing two combined contracts. In a practical sense, this paper can achieve the purpose of encouraging TPLSP to improve the level of fresh-keeping efforts and carbon emission reduction, consumers to improve freshness preference and environmental protection awareness and to expand market demand for high-quality fresh agricultural products. Then, this paper can promote the green and sustainable development of the fresh agricultural product supply chain and make a certain contribution to strengthening the ecological environmental protection and improving the overall social benefits.

3. Problem Statement

3.1. Problem Statement. As shown in Figure 1, this paper considers a three-stage fresh agricultural product supply chain consisting of a supplier, a retailer, and a third-party logistics service provider (TPLSP), where supply chain enterprises apply blockchain technology for a fee, and transaction cost is reduced by applying blockchain technology. TPLSP is the leading enterprise which provides services such as low-temperature storage and cold chain transportation to achieve the effect of keeping fresh products fresh. During this process, the electricity consumed by air-conditioned storage and cold storage is the main source of carbon emissions. Consumers have environmental protection.

Awareness and freshness preference, also doubt the emission reduction and freshness information provided by enterprises, thus affecting the market demand. TPLSP makes decisions about fresh product service price, carbon emission reduction level, and fresh-keeping effort; it publishes information such as carbon emission reduction level and freshness through the blockchain technology application platform, allowing consumers to use blockchain technology to trace the source of products, which, in turn improves Green trust level. Suppliers determine the wholesale price based on TPLSP and their own production costs, while retailers estimate market demand and determine the retail price based on TPLSP and suppliers' decisions.

Table 1: Survey of fresh agricultural product supply chain.

Reference	Supply chain system	Demand-influencing factors							Coordination contract	Consider low-carbon	Technology application
		Retail price	Fresh-keeping effort level	Carbon emission reduction level	Consumer green trust level	Consumer environment protection awareness	Consumer freshness preference	Others			
Ma et al. [39]	One supplier, one TPLSP, and one retailer	√	√	–	–	–	–	√	Revenue-and-cost-sharing contract	Y	N
Feng et al. [40]	One supplier and one retailer	√	√	–	–	–	–	–	Cost-sharing/revenue sharing and cost sharing/mixed coordination contract for cost-sharing and compensation strategies	N	N
Xie et al. [41]	One producer and one retailer	√	√	–	–	√	–	√	N	Y	N
Qin et al. [42]	One supplier and one retailer	√	√	–	–	–	–	√	Wholesale price contract and transfer payment	N	N
Yang and Yao [43]	One supplier and one retailer	√	√	√	–	√	√	–	Cost sharing contract and the two-part pricing contract	Y	N
Liao and Lu [44]	One producer, one supplier, and one retailer	√	–	–	–	–	–	√	Wholesale price/option contract	N	N
Wei and Huang [45]	One retailer and one manufacturer	√	–	–	–	–	–	√	Advance purchase discount contract and option contract	Y	Greening technology
Liu et al. [46]	One producer and one retailer	√	–	–	–	–	–	√	N	Y	Big data and blockchain
Yang et al. [47]	One supplier and one retailer	√	√	–	–	–	–	√	Revenue-sharing contract	N	N
Zhou et al. [48]	One agricultural cooperative and one supermarket	√	√	–	–	–	–	√	Two-part pricing contract	N	N
Jiang et al. [49]	One supplier and dual channel retailers	√	–	–	–	–	–	√	Cost-sharing contract	N	Blockchain
Liang and Hou [50]	One TPLSP and one retailer	√	√	–	–	–	–	√	Revenue-and-cost-sharing contract	N	N
This paper	One supplier, one TPLSP, and one retailer	√	√	√	√	√	√	–	“Revenue sharing + double cost sharing” and “two-part tariff + revenue sharing + double cost sharing” contract	Y	Blockchain

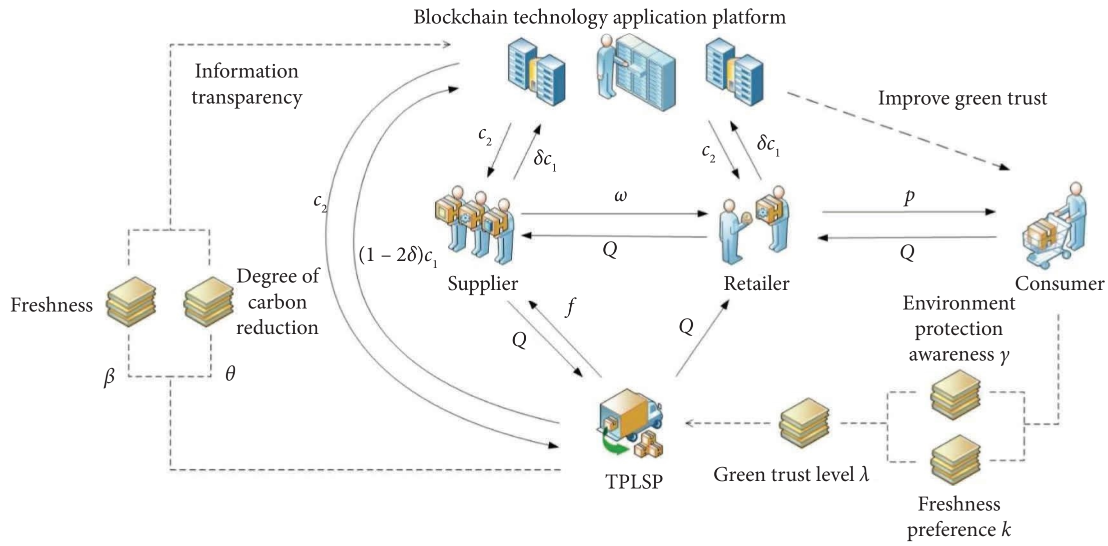


Figure 1: Operation model of fresh agricultural product supply chain based on blockchain technology.

3.2. Assumption. The relevant assumptions of this paper are as follows.

Assumption 1. The market information of the supplier and the retailer are completely symmetrical and the output of fresh products provided by the supplier is equal to the market demand, that is, the retailer does not have the problem of out-of-stock or inventory backlog.

Assumption 2. The market demand is simultaneously determined by the unit retail price of fresh products p, the carbon emission reduction level θ, the fresh-keeping effort level β, consumer environmental protection awareness γ, consumer freshness preference k, and consumer green trust level λ, $0 \leq \theta, \beta, \lambda \leq 1$. When no participant in the supply chain applies blockchain technology, the market demand functional form is $Q_1 = \alpha - p + \lambda\gamma\theta + \lambda k\beta$, while all participants in the supply chain apply blockchain technology; consumers can know the accurate carbon emission reduction level, product freshness, and other information, achieving a green trust level $\lambda = 1$, in which the market demand functional form is $Q_2 = \alpha - p + \gamma\theta + k\beta$.

Assumption 3. Investment in carbon emission reduction and fresh-keeping is a one-time investment which is not affected by demand. From existing literature, the quadratic cost function is widely used to describe the cost of carbon reduction and fresh-keeping. Therefore, the carbon emission reduction cost functional form in this paper is $C(\theta) = h\theta^2/2$ and the fresh-keeping cost functional form is $C(\beta) = b\beta^2/2$.

Assumption 4. In the supply chain enterprises' process of applying blockchain technology for information entry and traceability, the unit application cost of blockchain technology of the fresh product is c_1, and for each transaction process, the transaction cost saved per unit of fresh product is c_2. In the process of blockchain technology application, the application cost-sharing ratio of the supplier and the retailer is δ, and the ratio of blockchain technology application cost shared by TPLSP is $1 - 2\delta$, where $0 \leq \delta \leq 0.5$.

Assumption 5. To ensure a reasonable and feasible situation, we assume that $\alpha > c$, $c_1 < 3c_2 < c + c_1$, $hb > hk^2 + b\gamma^2$.

Assumption 6. In the following sections, we use π to represent the profits of the participants in the fresh agricultural product supply chain, the subscripts g, s, and t represent the supplier, the retailer, and the third-party logistics service provider, respectively, and the superscripts n, o, z, and d represent decentralized decision-making with or without the application of blockchain technology, centralized decision-making with or without the application of blockchain technology, respectively.

3.3. Notation. The notations involved in this paper and their meanings are shown in Table 2.

3.4. Model and Analysis. Considering the influence of factors such as the application cost of blockchain technology, environmental protection awareness, consumers' freshness preference, and green trust level, a three-stage game model consists of a supplier, a third-party logistics service provider, and a retailer is constructed. This paper first compares the decision-making and profits of the fresh agricultural product supply chain system under decentralized decision-making with and without the application of blockchain technology; for the situation where the benefits are higher, we analyze the supply chain participants' decisions and profits in the centralized decision-making mode. Based on such decisions and profits, the reason for the imbalance of the decentralized three-stage supply chain system is discussed, along with a reasonable and effective coordination contract formulated.

3.4.1. Decentralized Decision-Making Model When Blockchain Technology Is Not Applied. In the supply chain system

Table 2: List of notations.

Notation	Description
	Parameters
c	Unit production cost of fresh products
c_1	Unit application cost of blockchain technology of fresh products
c_2	After applying the blockchain technology, the transaction cost saved per unit of fresh products
h	Carbon emission reduction cost factor
b	Fresh-keeping cost factor
γ	Consumer environmental protection awareness
k	Consumer freshness preference
λ	Consumer green trust level, $0 \leq \lambda \leq 1$
α	Potential market scale
Q_1, Q_2	The fresh products demand when supply chain enterprises do not apply or apply blockchain technology
δ	The blockchain technology application cost-sharing ratio of supplier and retailer, $0 \leq \delta \leq 0.5$
η	The ratio of TPLSPs fresh-keeping costs shared by the supplier and the ratio of TPLSP carbon emission reduction costs shared by the retailer, $0 \leq \eta \leq 1$
φ	The ratio of revenue shared by the retailer to the supplier, $0 \leq \varphi \leq 1$
	Decision variables
ω	Unit wholesale price of fresh products
p	Unit retail price of fresh products
f	Unit service price of fresh products
θ	Carbon emission reduction level, $0 \leq \theta \leq 1$
β	Fresh-keeping effort level, $0 \leq \beta \leq 1$

under decentralized decision-making, each participant makes decisions with the ultimate goal of maximizing their own profits, which is a dynamic game process. First, the TPLSP takes its own profit maximization as the fundamental goal and determines the unit service price of fresh product f^n, carbon emission reduction level θ^n, and freshness preservation effort level β^n, which constitutes the first stage of the game; then, the supplier maximizes its own profit as the goal on the basis of TPLSP decision-making, determining the unit wholesale price w^n of fresh products, which constitutes the second stage; finally, the retailer decides to maximize its profits under the given f^n, θ^n, β^n, and w^n. In the decentralized decision-making supply chain model when blockchain technology is not applied, the profits functions of the retailer, the supplier, and theTPLSP are, respectively, as follows:

$$\pi_s^n = (p - \omega)(\alpha - p + \lambda\gamma\theta + \lambda k\beta), \quad (1)$$

$$\pi_g^n = (\omega - c - f)(\alpha - p + \lambda\gamma\theta + \lambda k\beta), \quad (2)$$

$$\pi_t^n = f(\alpha - p + \lambda\gamma\theta + \lambda k\beta) - \frac{1}{2}\left(h\theta^2 + b\beta^2\right). \quad (3)$$

Theorem 1. *In the decentralized decision-making model without the application of blockchain technology, the optimal unit service price of fresh products f^{n*}, the carbon emission reduction level θ^{n*}, the fresh-keeping effort level β^{n*}, the unit wholesale price w^{n*} of fresh product, the retail price p^{n*}, and optimal profits of each participant are as follows:*

$$\begin{aligned}
f^{n*} &= \frac{4(c-\alpha)hb}{\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb},\\
\theta^{n*} &= \frac{(c-\alpha)\lambda b\gamma}{\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb},\\
\beta^{n*} &= \frac{(c-\alpha)\lambda hk}{\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb},\\
\omega^{n*} &= \frac{c\lambda^2\left(hk^2 + b\gamma^2\right) - 2hb(3\alpha - c)}{\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb},\\
p^{n*} &= \frac{c\lambda^2\left(hk^2 + b\gamma^2\right) - hb(7\alpha - c)}{\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb},\\
\pi_s^{n*} &= \frac{[hb(\alpha - c)]^2}{\left(\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb\right)^2}\\
\pi_g^{n*} &= \frac{2[hb(\alpha - c)]^2}{\left(\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb\right)^2}\\
\pi_t^{n*} &= -\frac{(\alpha - c)^2hb}{2\left(\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb\right)}.
\end{aligned} \quad (4)$$

3.4.2. Decentralized Decision-Making Model When Blockchain Technology Is Applied. In the decentralized supply chain decision-making model when applying blockchain technology, the game process of each participant is the same as when blockchain technology is not applied. The retailer, the supplier, and the TPLSP need to undertake a certain ratio of blockchain technology applications cost, but transaction costs can be reduced, consumers understand the freshness and emission reduction level of fresh products well through product traceability, and the consumer green trust level $\lambda = 1$. In this case, the profit functions of the retailer, the supplier, and the TPLSP are

$$\begin{aligned}
\pi_s^o &= \left(p - \omega - \delta c_1 + c_2\right)(\alpha - p + \gamma\theta + k\beta),\\
\pi_g^o &= \left(\omega - c - f - \delta c_1 + c_2\right)(\alpha - p + \gamma\theta + k\beta),\\
\pi_t^o &= \left[f - (1 - 2\delta)c_1 + c_2\right]Q_2 - \frac{1}{2}\left(h\theta^2 + b\beta^2\right).
\end{aligned} \quad (5)$$

Theorem 2. *In the decentralized decision-making model when applying blockchain technology, there exists the optimal unit service price of fresh product f^{o*}, carbon emission reduction level θ^{o*}, fresh-keeping effort level β^{o*}, the unit wholesale price w^{o*} of fresh product w^{o*}, the retail price p^{o*}, and optimal profit of each participant as follows:*

$$f^{o*} = \frac{4(c-\alpha)hb + c_1(1-2\delta)\left(hk^2+b\gamma^2\right) + 4c_1(4\delta-1)hb - c_2\left(hk^2+b\gamma^2+4hb\right)}{hk^2+b\gamma^2-8hb},$$

$$\theta^{o*} = \frac{(c+c_1-3c_2-\alpha)b\gamma}{hk^2+b\gamma^2-8hb}, \tag{6}$$

$$\beta^{o*} = \frac{(c+c_1-3c_2-\alpha)hk}{hk^2+b\gamma^2-8hb},$$

$$\omega^{o*} = \frac{\left[c_1(1-\delta)+c-2c_2\right]\left(hk^2+b\gamma^2\right) - 2hb\left(3\alpha+c_1-4\delta c_1+c+c_2\right)}{hk^2+b\gamma^2-8hb} \tag{7}$$

$$\begin{aligned} p^{o*} &= \frac{c_1\left(hk^2+b\gamma^2\right)+(c-3c_2)\left(hk^2+b\gamma^2-hb\right)-hb(7\alpha+c_1)}{hk^2+b\gamma^2-8hb}, \\ \pi_s^{o*} &= \frac{(c+c_1-3c_2-\alpha)^2h^2b^2}{\left(hk^2+b\gamma^2-8hb\right)^2}, \\ \pi_g^{o*} &= \frac{2(c+c_1-3c_2-\alpha)^2h^2b^2}{\left(hk^2+b\gamma^2-8hb\right)^2}, \\ \pi_t^{o*} &= -\frac{(c+c_1-3c_2-\alpha)^2hb}{2\left(hk^2+b\gamma^2-8hb\right)}. \end{aligned} \tag{8}$$

Lemma 1

(i) $\theta^{o*} > \theta^{n*}$; $\beta^{o*} > \beta^{n*}$; $\pi_s^{o*} > \pi_s^{n*}$; $\pi_g^{o*} > \pi_g^{n*}$; $\pi_t^{o*} > \pi_t^{n*}$

(ii) *When* $\delta < (c_1-c_2)(hk^2+b\gamma^2) - A/2c_1$, $f^{o*} > f^{n*}$, *where* $A = 4hb(2\alpha-2c+c_1+c_2)$

(iii) *When* $\delta > (hk^2+b\gamma^2)B - 2hb(c_1+c_2)/c_1(hk^2-8hb+b\gamma^2)$, $\omega^{o*} < \omega^{n*}$, *where* $B = (c+c_1-2c_2-c\lambda^2)$

(iv) *When* $hk^2+b\gamma^2 > (3c_2-c_1)hb/3c_2-c+c_1+c\lambda^2$, $p^{o*} > p^{n*}$, *on the contrary,* $p^{o*} < p^{n*}$

Lemma 1 demonstrates that compared with the situation where blockchain technology is not applied, when blockchain technology is applied, TPLSP will improve the carbon emission reduction level and fresh-keeping efforts and the optimal profits of the retailer, the supplier, and the TPLSP will increase; when the blockchain technology application cost-sharing ratio of the supplier and the retailer is lower than a certain value, that is, when the ratio of blockchain technology application cost that TPLSP undertakes is high enough, TPLSP will increase the service price to ensure that its own interests are protected; when the cost-sharing ratio of blockchain technology application is higher than a certain value, the service price given by the supplier to the TPLSP will be significantly reduced, and the wholesale price given by the retailer to the supplier will also be reduced. In order to maximize their own profits, the retailer will reduce retail prices to increase market demand; when environmental protection awareness and freshness preference are higher than a certain value, with a high market demand caused by consumers' green trust level reaching 1 due to the application of blockchain technology, the retailer can increase price appropriately. On the contrary, if environmental protection awareness and freshness preference are low, the retailer can only increase market demand by reducing the retail price because of information transparency.

3.4.3. Centralized Decision-Making Model When Blockchain Technology Is Applied. Under the centralized decision-making model, participants in the supply chain take the maximization of system profits as the fundamental goal to make a unified decision as a whole on the level of carbon emission reduction, the fresh-keeping effort level, and the unit retail price of fresh products. Since Lemma 1 has proved that the retailer, the supplier and the TPLSP have higher profits when applying blockchain technology; that is, the total profits of the supply chain system are higher; so this paper considers the centralized decision-making of supply chain enterprises when applying blockchain technology, and the total profits of the fresh agricultural product supply chain is as follows:

$$\pi^z = \left[p-c-c_1+3c_2\right]Q_2 - \frac{1}{2}\left(h\theta^2+b\beta^2\right). \tag{9}$$

Theorem 3. *In the centralized decision-making model when applying blockchain technology, the optimal carbon emission reduction level* θ^{z*}*, fresh-keeping effort level* β^{z*}*, unit retail price of fresh product* p^{z*}*, and total profits of the supply chain are as follows:*

$$\theta^{z*} = \frac{(c + c_1 - 3c_2 - \alpha)b\gamma}{hk^2 + b\gamma^2 - 2hb},$$
$$\beta^{z*} = \frac{(c + c_1 - 3c_2 - \alpha)hk}{hk^2 + b\gamma^2 - 2hb},$$
$$p^{z*} = \frac{C - hb(\alpha + c + c_1 - 3c_2)}{hk^2 + b\gamma^2 - 2hb}, \quad (10)$$
$$\pi^{z*} = -\frac{(c + c_1 - 3c_2 - \alpha)^2 hb}{2(hk^2 + b\gamma^2 - 2hb)},$$

where $C = (c + c_1 - 3c_2)(hk^2 + b\gamma^2)$.

Lemma 2. $p^{z*} < p^{o*}$; $\theta^{z*} > \theta^{o*}$; $\beta^{z*} > \beta^{o*}$; $\pi^{z*} > \pi_s^{o*} + \pi_g^{o*} + \pi_t^{o*}$.

Lemma 2 demonstrates that when applying blockchain technology, the retail price of fresh products under centralized decision-making is lower than the optimal price under decentralized decision-making, but the carbon emission reduction level and fresh-keeping effort level of TPLSP are higher than those of decentralized decision-making, and the total profits of the supply chain under centralized decision-making is higher than the sum of the optimal profits of the retailer, the supplier, and TPLSP under decentralized decision-making. This is because, in the centralized decision-making mode, the retailer chooses to reduce retail prices with the goal of maximizing the overall profits of the supply chain. Since consumers can trace the source of products using the blockchain technology, carbon emission reduction information and fresh-keeping information are both transparent. Therefore, TPLSP will promote environmental protection awareness and freshness preference by improving the level of carbon emission reduction and fresh-keeping effort, which will significantly increase the market demand for fresh products, resulting in the optimal profits increase of the three-stage supply chain system composed of the retailer, the supplier, and the TPLSP.

Lemma 3

(i) f^{o*} *and* ω^{o*} *increase with the increase of transaction cost saved by the application of blockchain technology, consumers' environmental protection awareness, and freshness preference and decrease with the increase of unit production cost of fresh products, carbon emission reduction factor, and fresh-keeping cost factor. When* $\delta < hk^2 + b\gamma^2 - 4hb/hk^2 + b\gamma^2 - 16hb$, f^{o*} *increases with the increase of the application cost of blockchain technology and vice versa; when* $\delta > hk^2 + b\gamma^2 - 2hb/hk^2 + b\gamma^2 - 8hb$, ω^{o*} *decreases with the increase of the application cost of blockchain technology and vice versa.*

(ii) p^{o*} *and* p^{z*} *increase with the increase of the unit production cost of fresh products, the application cost of blockchain technology, consumers' environmental protection awareness, and freshness preference and decrease with the increase of the transaction cost, carbon emission reduction cost factor, and fresh-keeping cost factor.*

(iii) θ^{o*}, θ^{z*}, β^{o*}, *and* β^{z*}, *along with the profits of each participant under decentralized decision-making and the total profits of the system under centralized decision-making decrease with the increase of the unit production cost of fresh products, application cost of blockchain technology, carbon emission reduction cost factor, and fresh-keeping cost factor, increase with the increase of the transaction cost savings of applying blockchain technology, consumers' environmental protection awareness, and freshness preference.*

Lemma 3 demonstrates that when the blockchain technology application cost-sharing ratio of the supplier and the retailer is higher than a certain value, with the increase of blockchain technology application costs, the retailer is more reluctant to pay the higher wholesale price to the supplier, resulting in a lower service price paid to the TPLSP by the supplier. In any case, due to the increase in the unit production cost of fresh products, the application cost of blockchain technology, and the reduction of transaction cost saved by the application of blockchain technology, to ensure that their own profits are protected, the retailer will increase retail prices and the TPLSP will reduce carbon emission reduction and fresh-keeping effort level. Similarly, if the carbon emission reduction cost factor and the fresh-keeping cost factor increase, the TPLSP will choose to reduce the carbon emission reduction level and the fresh-keeping effort level for the purpose of maximizing its own profits, causing negative effects such as reducing consumers' environmental protection awareness, freshness preference, and market demand. The retailer will maximize their own benefits by lowering the retail price and increasing demand; however, the inevitable reduction of market demand will still damage the profits of the retailer, the supplier, and the TPLSP in the supply chain. On the contrary, the improvement of consumers' environmental protection awareness and freshness preference will increase market demand, and the retailer can appropriately increase the retail price and are more willing to pay the higher wholesale price to the supplier, which will also increase the service price obtained by the TPLSP.

3.5. Coordinating the Supply Chain. Under the situation of decentralized decision-making applying the blockchain technology, due to the contradiction between the individual profits and the system profit, the decision-making in the supply chain cannot reach an optimal condition, resulting in damage to the overall profits of the supply chain. Through effective contract coordination, the TPLSP can be willing to reach the carbon emission reduction level and fresh-keeping effort level under the centralized decision-making, resulting in higher economic profits for supply chain enterprises and the system than the optimal level under decentralized decision-making, achieving a Pareto improvement. Therefore, this paper designs a contract incentive mechanism to coordinate the supply chain system.

3.5.1. "Revenue Sharing + Double Cost Sharing" Contract. In order to motivate the retailer to increase their order quantity, the supplier can first give the retailer a wholesale price discount ω^{d*}; meanwhile, to make up for the supplier price loss, the retailer can return a ratio φ of the sales revenue to the supplier; by sharing a ratio η of the TPLSP fresh-keeping cost can the supplier improve the freshness of fresh products, thereby attracting the retailer to order more products. At the same time, the TPLSP should provide the supplier with a service price discount to maintain a long-term cooperative relationship between the two parties. Finally, the retailer as the direct beneficiaries of the increased demand for fresh products should share the carbon emission reduction costs of the TPLSP in order to motivate them to make greater emission reduction efforts. Under this contract, the profit functions of the retailer, the supplier, and the TPLSP are as follows:

$$\pi_s^d = (1-\varphi)(p-\omega-\delta c_1+c_2)Q_2 - \frac{1}{2}\eta h\theta^2, \tag{11}$$

$$\pi_g^d = [\varphi p + (1-\varphi)\omega - c + (1+\varphi)(c_2-\delta c_1) - f]Q_2 - \frac{1}{2}\eta b\beta^2, \tag{12}$$

$$\pi_t^d = \frac{[f-(1-2\delta)c_1+c_2]Q_2 - (1-\eta)\left(h\theta^2+b\beta^2\right)}{2}. \tag{13}$$

Theorem 4. *Under the contract of "revenue sharing + double cost sharing," there are optimal unit service price of fresh product f^{d*}, carbon emission reduction level θ^{d*}, fresh-keeping effort level β^{d*}, wholesale price w^{d*}, retail price of fresh product p^{d*}, and optimal profit of each participant are as follows:*

$$f^{d*} = \frac{D+2hb[(\alpha-c)(1-\varphi)+E]}{hk^2+b\gamma^2-2hb}, \tag{14}$$

where $D=(c_1-2\delta c_1-c_2)(hk^2+b\gamma^2)$ and $E=c_1(2\delta+\varphi-2)+c_2(4-3\varphi)$;

$$\omega^{d*} = c+c_1-\delta c_1-2c_2, \tag{15}$$

$$\pi_s^{d*} = -\frac{hbC\left[2(\varphi-1)h+\eta\gamma^2\right]}{2\left(hk^2+b\gamma^2-2hb\right)^2}, \tag{16}$$

$$\pi_g^{d*} = -\frac{hbC\left[2(\varphi-2)b+\eta k^2\right]}{2\left(hk^2+b\gamma^2-2hb\right)^2}, \tag{17}$$

$$\pi_t^{d*} = \frac{F\left[4(\varphi-1)hb+\left(hk^2+b\gamma^2\right)(\eta-1)\right]}{2\left(hk^2+b\gamma^2-2hb\right)^2}, \tag{18}$$

where $F=(c+c_1-3c_2-\alpha)^2hb$.

Lemma 4

(1) *The optimal profits of the supply chain system after the "revenue sharing + double cost sharing" contract coordination is equal to the optimal profits under the centralized decision-making mode*

(2) *When $0<\varphi\leq\varphi_1$, $0<\eta\leq 1$ or $\varphi_1<\varphi<\varphi_2$, $0<\eta<\eta_1$, and $\pi_s^{d*}>\pi_s^{o*}$; when $0<\varphi<1$, $0<\eta<1$, and $\pi_g^{d*}>\pi_g^{o*}$; when $0<\varphi<1$, $0<\eta<1$, and $\pi_t^{d*}<\pi_t^{o*}$*

$$\begin{aligned}
\varphi_1 &= \frac{24h^3b\left(k^2-5b\right)+h^2\gamma^2\left(k^4-16k^2b+88b^2\right)+G}{2h\left(hk^2+b\gamma^2-8hb\right)^2}, \text{ where } G = b\gamma^4\left(2hk^2-16hb+b\gamma^2\right),\\
\varphi_2 &= -\frac{12hb\left(2hk^2-5hb+b\gamma^2\right)}{\left(hk^2+b\gamma^2-8hb\right)^2};\ \eta_1 = -\frac{H+12hb\left(hk^2-5hb+b\gamma^2\right)}{\left(hk^2+b\gamma^3-8hb\right)^2}, \text{ where } H = 2h\left[\varphi\left(hk^2-8hb+b\gamma^2\right)\right]^2.
\end{aligned} \tag{19}$$

Lemma 4 demonstrates that after the coordination of the "revenue sharing + double cost sharing" contract, the total profits of the supply chain system is equal to the optimal profits of the system under centralized decision-making and the contract can improve the optimal profits of the retailer and the supplier. However, it reduces the optimal profit of the TPLSP, which is mainly because the service price given by the supplier to the TPLSP will be significantly reduced. Therefore, the TPLSP could not maximize its own profits and will decline such a contract. It can be seen that the contract of "revenue sharing + double cost sharing" alone cannot achieve the coordination of the supply chain.

3.5.2. "Two-Part Tariff + Revenue Sharing + Double Cost Sharing" Contract. It can be seen from Lemma 4 that the contract of "revenue sharing + double cost sharing" can coordinate the total profits of the supply chain system and improve the optimal profits of the retailer and the supplier, but it will reduce the optimal profits of the TPLSP. Therefore, in this section, we add a "Two-part tariff" to the "revenue sharing + double cost sharing" contract; that is, the retailer and the supplier need to pay a certain amount of fixed fees T_1 and T_2 to the TPLSP, respectively, so as to realize Pareto improvement of the economic profits of all participants and a coordinated supply chain system, where the following theorems can be obtained.

Lemma 5. *When φ, η, T_1, and T_2 meet the following conditions, the three-stage fresh agricultural product supply chain can achieve perfect coordination:* $0 < \varphi \le \varphi_1$, $0 < \eta \le 1$ *or* $\varphi_1 < \varphi < \varphi_2$, $0 < \eta < \eta_1$, $0 < T_1 < \min\{T_{11}, T_{12}\}$, *and* $T_{22} < T_2 < T_{21}$.

$$T_{11} = \frac{IJb + 24h^2b\left(hk^2 + b\gamma^2 - 5hb\right) + M}{2\left(hk^2 + b\gamma^2 - 8hb\right)^2\left(hk^2 + b\gamma^2 - 2hb\right)^2}; T_{12} = \frac{-IM - \left(hk^2 + b\gamma^2\right)\left(hk^2 + b\gamma^2 - 8hb\right)\eta}{2\left(hk^2 + b\gamma^2 - 8hb\right)^2\left(hk^2 + b\gamma^2 - 2hb\right)^2};$$
$$T_{21} = \frac{IJh + 48hb^2\left(hk^2 + b\gamma^2 - 5hb\right) + k^2L}{2\left(hk^2 + b\gamma^2 - 8hb\right)^2\left(hk^2 + b\gamma^2 - 2hb\right)^2}; T_{22} = \frac{\left(h^3k^2 + b^3\gamma^2\right)K + h^3b^3N + h^3k^2T_1O + P + V}{2\left(hk^2 + b\gamma^2 - 8hb\right)^2\left(hk^2 + b\gamma^2 - 2hb\right)^2}, \quad (20)$$

where $I = (c + c_1 - 3c_2 - \alpha)^2hb$, $J = [2\varphi h(hk^2 + b\gamma^2 - 2hb)]^2$, $K = \varphi h^2b^2(36c_2^2 - 24c_1c_2 + 4c_1^2)$, $L = \eta(hk^2 + b\gamma^3 - 8hb)^2$, $M = 4hb[\varphi h(k^2 - 8b) + 9hb + \varphi b\gamma^2]$, $N = (324 - 288\varphi)c_2^2 + -64T_1(192\varphi - 216)c_1c_2 + (36 - 32\varphi)c_1^2$, $O = 2k^4 - 24bk^2 + 72b^2$, $P = 6h^2bT_1\gamma^2(k^4 - 8k^2b + 24b^2)$, $R = 3hk^2 - 12hb + b\gamma^2$, $S = (\alpha - c)^2 - 2(c + \alpha)(3c_2 - c_1)$, $U = \eta(-hk^2 + 8hb - b\gamma^2)(hk^2 + b\gamma^2)$, *and* $V = 2b^2T_1\gamma^4R + hbKS - IU$.

Lemma 5 demonstrates that when the parameters of the "two-part tariff + revenue sharing + double cost sharing" contract are controlled within a feasible threshold, the three-stage fresh agricultural product supply chain system can achieve perfect coordination.

4. Results

In order to further verify the effectiveness and practicability of various decisions, profits factors, and coordination contracts in the three-stage fresh agricultural product supply chain constructed mentioned above, this paper uses Matlab2021a software to simulate and analyze relevant parameters. Without loss of generality, under the condition that the model assumptions and the Hessian matrix results are satisfied, the parameter value range is set, and the parameter assignments of the literature [35] are referenced, assuming $\alpha = 10$, $c = 2$, $c_2 = 0.5$, $h = 20$, $b = 20$, $\varphi = 0.2$, and $\eta = 0.3$.

4.1. Analysis of Influencing Factors of Supply Chain System Decision and Profit

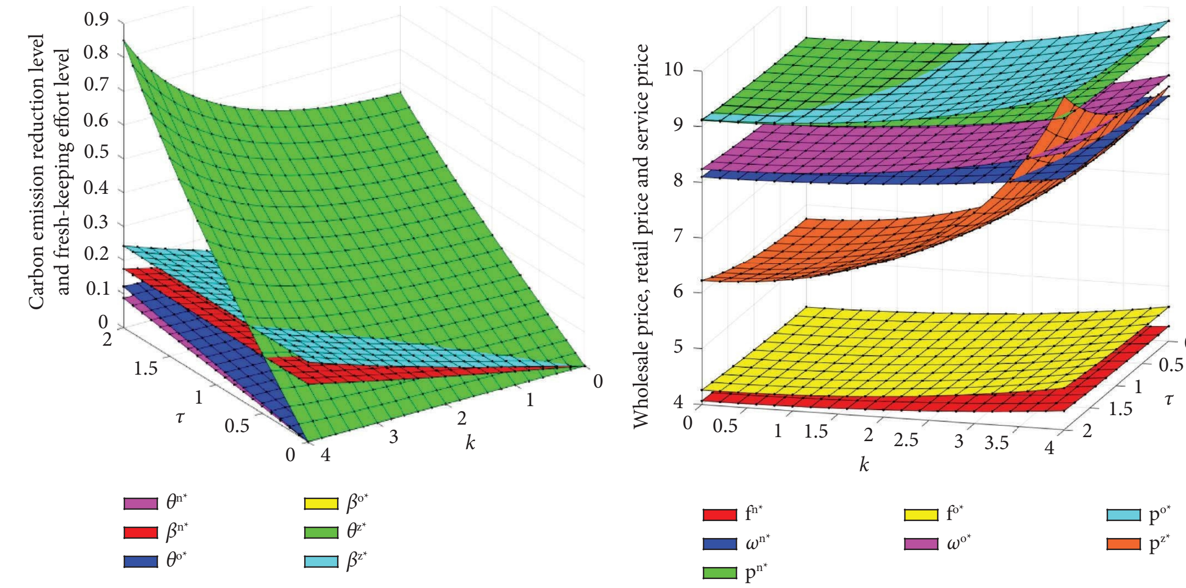
4.1.1. Consumer Environmental Protection Awareness and Freshness Preference. In order to more intuitively show the influence of consumer environmental protection awareness and freshness preference on the decision-making of the supply chain system, on the basis of the above parameter assignments, set $c_1 = 1$, $\delta = 0.3$, and $\lambda = 0.8$, the obtained results are shown in Figures 2(a) and 2(b).

As shown in Figures 1 and 2, in any decision-making mode, each decision variable will increase with the improvement of environmental protection awareness and freshness preference, but the environmental protection awareness has a lower impact on the fresh-keeping effort level, and freshness preference has a lower impact on carbon emission reduction level. When consumers' environmental protection awareness and freshness preference are low, under decentralized decision-making, the optimal retail price when blockchain technology is applied is lower than the optimal price when blockchain technology is not applied and vice versa; when consumers' environmental protection awareness and freshness preference are higher than a certain value, the retail price of applying blockchain technology under decentralized decision-making is the highest, which is in line with the conclusions of Lemmas 1(iv) and 2. The optimal value of each decision variable is the highest in the centralized decision-making mode, the second is the application of blockchain technology under decentralized decision-making, and the lowest when blockchain technology is not applied, which shows that the application of blockchain technology can improve the economic profits of the supply chain system.

4.1.2. Consumer Green Trust Level, Blockchain Technology Application Cost, and Sharing Ratio. In order to more intuitively show the impact of green trust level, blockchain technology application cost, and sharing ratio on the decision-making and profits of the supply chain system, the same as the above-given parameter assignment, the obtained results are shown in Figures 3(a)–3(e).

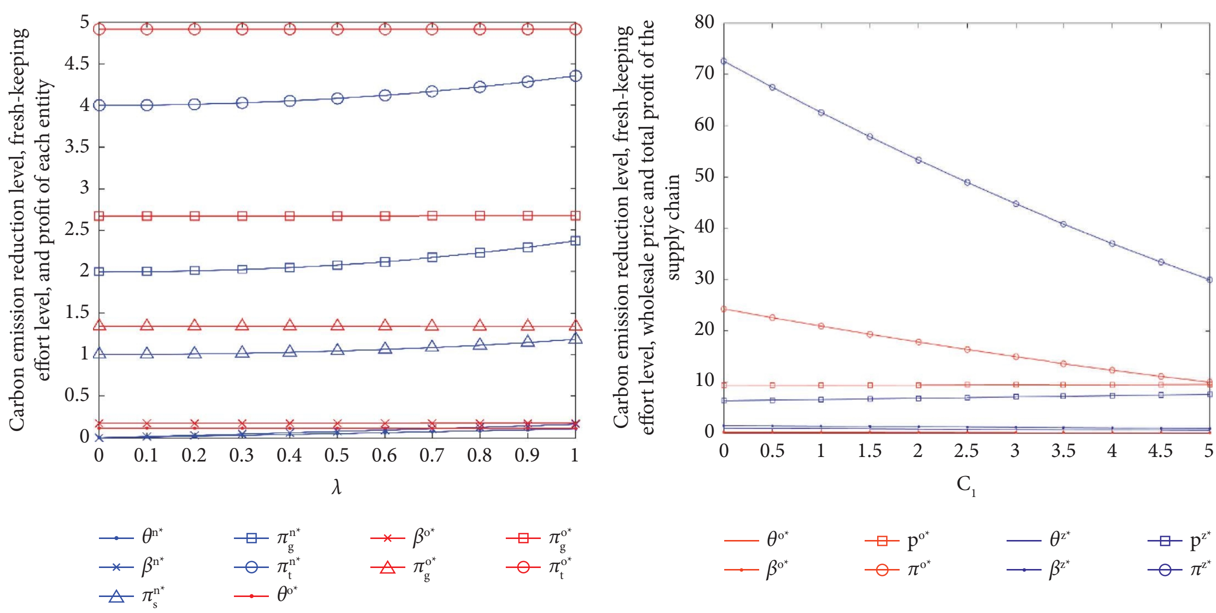
As can be seen from Figure 3(a), the optimal carbon emission reduction level, fresh-keeping effort level, and the profits of each participant are positively correlated with the green trust level of consumers when the blockchain technology is not applied under decentralized decision-making. When the blockchain technology is applied, the consumer green trust level is 1, so θ^{o*}, β^{o*}, π_s^{o*}, π_s^{o*}, and π_t^{o*} have nothing to do with λ and are higher than the optimal results when the blockchain technology is not applied; as can be seen from Figure 3(b), the optimal carbon emission reduction level, fresh-keeping effort level, and supply chain system profits when applying blockchain technology are all negatively correlated with the application cost of blockchain technology, but the retail price is positively correlated with it, and the optimal carbon emission reduction level, fresh-keeping effort level, and total profits of the supply chain system under centralized decision-making are higher, and the retail price is lower.

Figure 3(d) shows that when the blockchain technology application cost-sharing ratio of the supplier and the retailer is less than a certain value, f^{o*} and ω^{o*} increase with the increase of c_1. On the contrary, when the blockchain technology application cost-sharing ratio of the TPLSP is



(a) (b)

Figure 2: Effects of γ and k on supply chain system decisions.



(a) (b)

Figure 3: Continued.

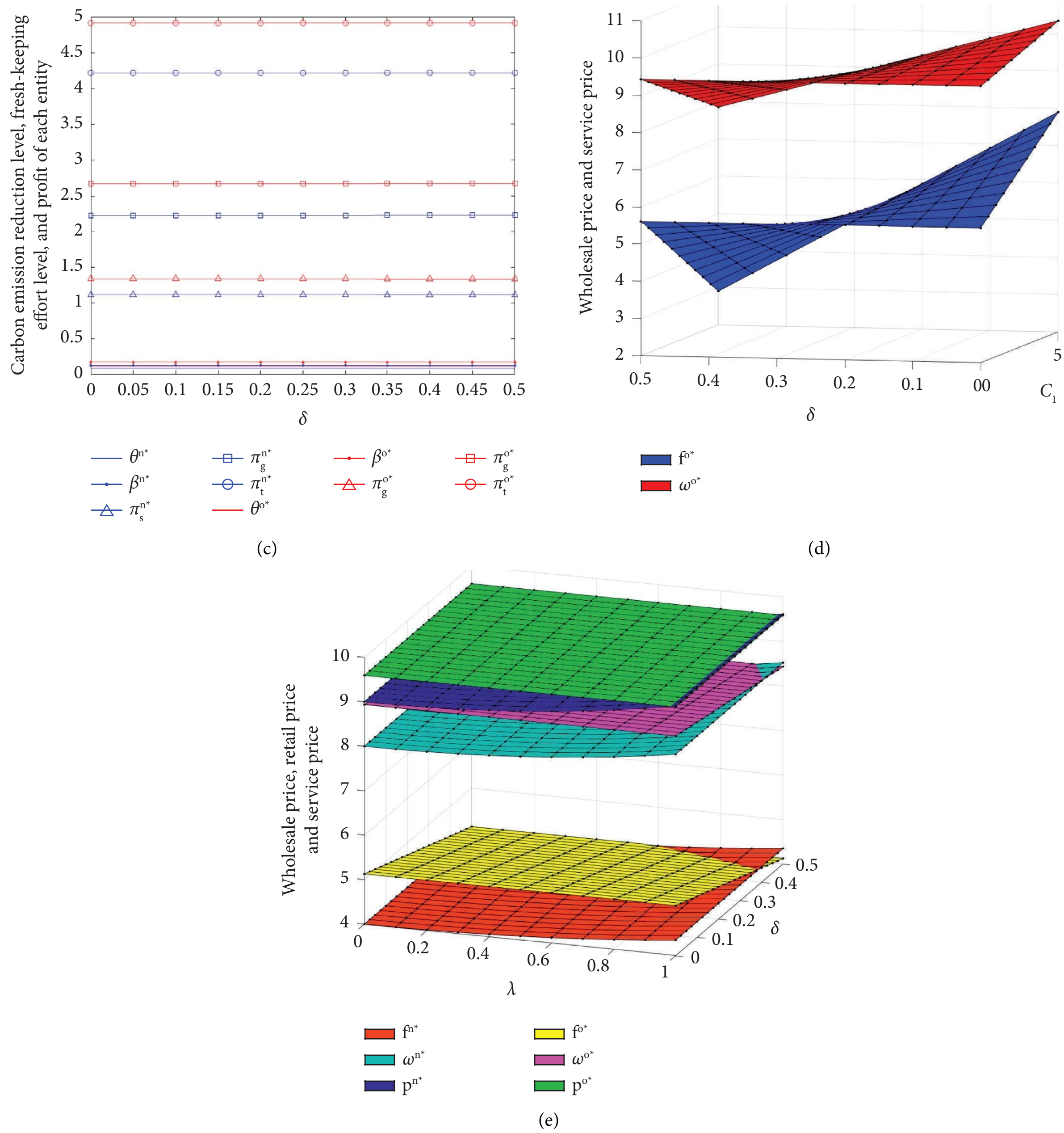


Figure 3: Effects of λ, c_1, and δ on supply chain system decisions and profits.

less than a certain value, f^{o*} and ω^{o*} decrease with the increase of c_1, which is consistent with the conclusion of Lemma 3(i). This shows that the supplier and the TPLSP will make corresponding adjustments to their own decisions according to the changes in the application cost of blockchain technology. Therefore, as shown in Figure 3(c), the optimal carbon emission reduction level, fresh-keeping effort level, and the profits of each participant have nothing to do with δ under decentralized decision-making.

As can be seen from Figure 3(e), when the blockchain technology is not applied, the unit wholesale price and service price of fresh products are positively correlated with the green trust level, and when the supplier's blockchain technology application cost-sharing ratio is greater than a certain value, $f^{n*} > f^{o*}$, $\omega^{n*} > \omega^{o*}$, and $p^{n*} > p^{o*}$, it is consistent with the conclusions of Lemmas 1(ii)–1(iv). This shows that when δ is high, the TPLSP only needs to pay a lower application cost of blockchain technology, and from the perspective of maximizing the overall profits of the supply chain, the service price will be reduced. Therefore, the supplier will also reduce the wholesale price so that the retailer can sell fresh products at lower prices, thereby increasing market demand and improving system economic profits.

4.2. The Impact of Coordination Contracts on Supply Chain System Decisions and Profits

4.2.1. "Revenue Sharing + Double Cost Sharing" Contract. Figure 4(a) depicts the impact of the "revenue sharing + double cost sharing" contract on wholesale prices and service prices as the unit production cost of fresh products changes. It can be seen from the figure that the wholesale price and service price after contract coordination are lower than the optimal decision results under centralized decision-making, which shows that in order to make the retailer reduce retail prices and increase market demand, both f and ω are significantly lower, and $f^{d*} < 0$ means that the TPLSP not only does not charge service prices but also gives certain subsidies to the supplier. As shown in Figure 4(b), the maximum profits of the retailer and the supplier after contract coordination is higher than the optimal result under decentralized decision-making. The maximum profits of the TPLSP are lower than the optimal result under decentralized decision-making, and the profits of the TPLSP increase with the increase of the production cost of fresh products, while the profits of the supplier and the retailer decrease with the increase of production cost.

Figure 4(c) depicts the trend of changes in the ratio of fresh-keeping costs shared by the supplier, the ratio of carbon emission reduction costs shared by the retailer, and the ratio of revenue shared by the retailer with the change of carbon emission reduction costs. Substitute φ_1 and φ_2 into η_1 to get η_{11} and η_{12}, as shown in the figure; there are always $\varphi_1 < \varphi_2$, $\eta_{11} = 1$, and $\eta_{12} \approx 0$; that is, when $0 < \varphi \leq \varphi_1$ and $0 < \eta < \eta_{11} = 1$ and when $\varphi_1 < \varphi < \varphi_2$ and $0 < \eta < \eta_{12} = 0$. This means that if the ratio of revenue shared by the retailer is higher than a certain value, they will not share the carbon emission reduction cost of the TPLSP, so that the TPLSP will not give service price discounts to the supplier so that the supplier will also not share the TPLSP fresh-keeping cost. The contract eventually evolved into a "wholesale price + revenue sharing" contract between the retailer and the supplier, which can also explain why the contract can improve the profits of the retailer and the supplier but will hurt the profits of the TPLSP. Therefore, the perfect coordination of the supply chain system cannot be achieved only through the contract of "revenue sharing + double cost sharing."

4.2.2. "Two-Part Tariff + Revenue Sharing + Double Cost Sharing" Contract. Figure 5(a) depicts the changing trends of T_1 and T_2 with carbon emission reduction costs in the contract of "two-part tariffs + revenue sharing + double cost sharing." Substitute T_{11} and T_{12} into T_{22} to get T_{22}^1 and T_{22}^2, As shown in the figure, there are always, $T_{12} > T_{11}$ and $T_{21} > T_{22}^1 > T_{22}^2$. Therefore, the feasible conditions of the coordination contract are: $0 < T_1 < T_{11}$ and $T_{22}^1 < T_2 < T_{21}$, which is consistent with the conclusion of Lemma 5. Figures 5(b)–5(d) describe the effects of T_1 and T_2 on the profits of each participant in the supply chain system. After contract coordination, the retailer's profits increase with the decreases of T_1, and the supplier's profits increase with the decreases of T_2, and the TPLSP's profits increase with the increases of T_1 and T_2. In the case of parameter setting in this paper, as shown in the figure, when $T_1 < 29.2416$ and $\pi_s^{d*} > \pi_s^{o*}$, when $T_2 < 66.0408$ and $\pi_g^{d*} > \pi_g^{o*}$, and when $T_1 > 15$ and $T_2 > 47$, $\pi_t^{d*} > \pi_t^{o*}$. Therefore, when $15 < T_1 < 29.2416$ and $47 < T_2 < 66.0408$, always have $\pi_s^{d*} \geq \pi_s^{o*}$, $\pi_g^{d*} \geq \pi_g^{o*}$, and $\pi_t^{d*} \geq \pi_t^{o*}$. That is, the contract of "two-part tariff + revenue sharing + double cost sharing" can realize the Pareto improvement of the profits of each participant in the three-stage fresh agricultural product supply chain system and achieve perfect coordination.

5. Managerial Insights and Practical Implications

5.1. Practical Implications. Fresh agricultural products are not easy to store and have strong timeliness. During transportation and storage, they have high requirements for refrigeration technology and thermal insulation technology, resulting in a very high level of carbon emissions in circulation. With the improvement of consumers' freshness preference and environmental protection awareness and the country's emphasis on carbon emissions, enterprises at each node of the fresh agricultural product supply chain must not only consider improving freshness to increase economic profits but also consider the social responsibility of low-carbon emission reduction. The application of blockchain technology can enable consumers to understand the real fresh-keeping information and emission reduction information of enterprises, improve consumers' green trust level, and then expand the market demand for fresh agricultural products. Therefore, based on the dual perspectives of blockchain and low carbon, this paper considers factors such as the fresh-keeping cost, carbon emission reduction cost, and the blockchain technology application cost-sharing ratio into the research on the coordination of the fresh agricultural products supply chain. By comparing the optimal decision-making and profit of the supply chain under the three decision-making modes, this paper provides a reliable theoretical reference for the application of blockchain technology in the supply chain. By designing a reasonable coordination contract, we can achieve a cooperative relationship between enterprises in the supply chain and finally achieve the optimal overall efficiency of the supply chain and the Pareto improvement of the profits of each participant and also further encourage the third-party logistics service providers to make the greatest efforts to freshness-keeping and carbon emission reduction in transportation and storage. Therefore, this research has important practical significance for the economic development and ecological civilization construction of the whole society.

5.2. Managerial Insights. On the basis of the practical implications mentioned above, the management implications of this paper can be concluded as follows:

(1) Environmental protection awareness and freshness preference are important factors to motivate enterprises in the supply chain of fresh agricultural products to produce, transport, and sell. Enterprises can use media such as radio and television to vigorously

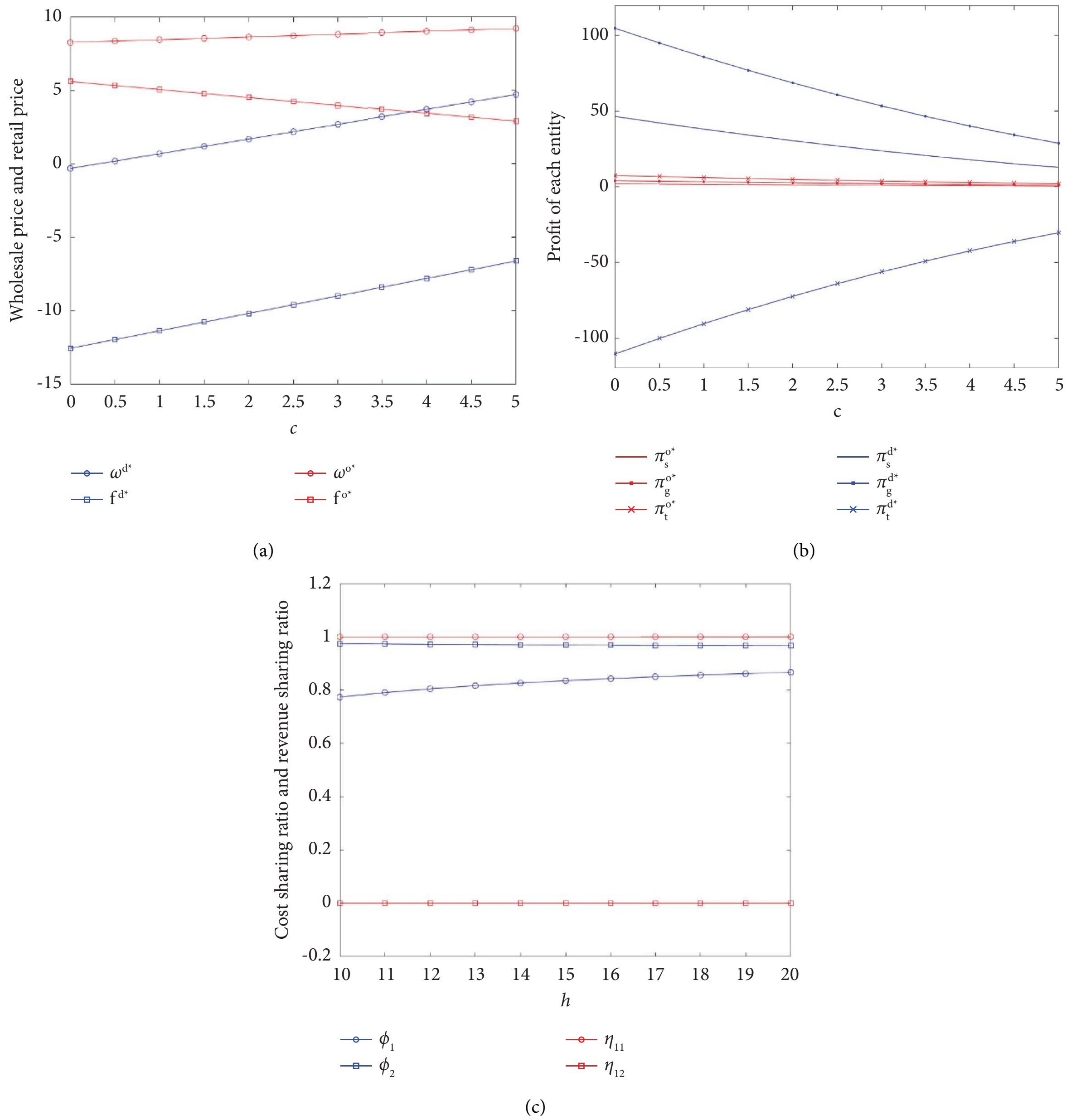


FIGURE 4: “Revenue sharing + double cost sharing” contract change trend and its impact on profits.

publicize the concept of sustainable development and encourage consumers to form a low-carbon and green consumption concept. The government can consider giving corresponding price subsidies to fresh agricultural products with low-carbon delivery and high freshness to meet people’s demand for high-quality dairy products and logistic services.

(2) The green trust level plays a decisive role in whether consumers buy fresh and low-carbon fresh agricultural products. Enterprises in the supply chain should apply blockchain technology to ensure emission reduction and transparency of fresh-keeping information to improve consumers’ green trust level and expand the supply of high-quality fresh agricultural products.

(3) Enterprises in the fresh agricultural product supply chain applying blockchain technology should reasonably decide the cost-sharing ratio, subsidies are given by the government to reduce the cost of blockchain technology application, so as to increase the carbon emission reduction level, the fresh-keeping effort level, and the profits of various participants, thereby ensuring the quality and safety of fresh products and achieving carbon peaking and carbon neutrality for fresh agricultural products.

(4) Under the decentralized decision-making mode in the supply chain system, the optimal profit of TPLSPs is always higher than the maximum profit of suppliers and retailers. Therefore, TPLSPs can be the organization enterprises for the contract

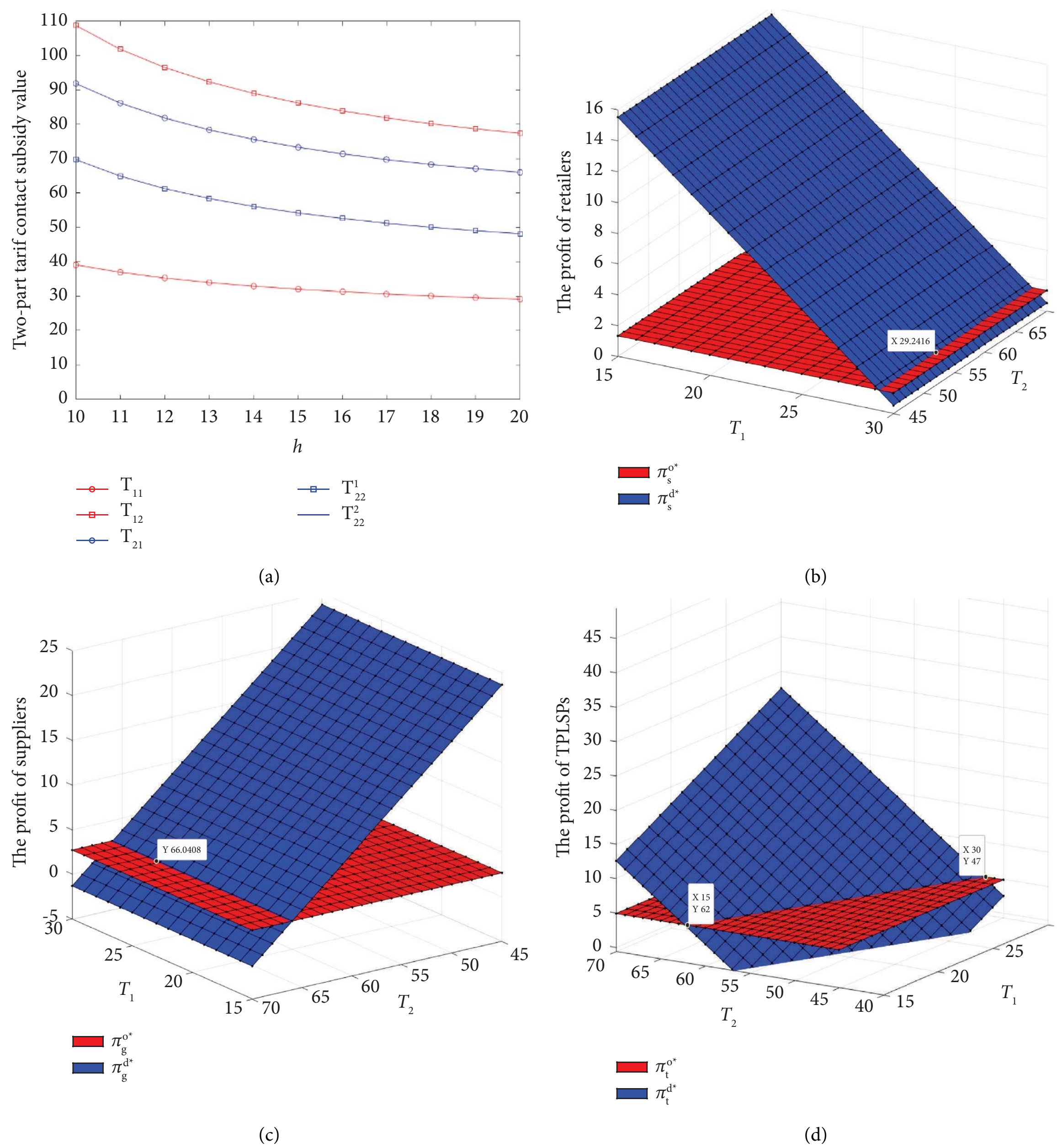


Figure 5: "Two-part tariff + revenue sharing + double cost sharing" contract change trend and its impact on profits.

coordination mechanism of "two-part tariff + revenue sharing + double cost sharing," lead suppliers and retailers to coordinate according to the agreement, so that the tripartite decision-making participant can obtain greater profits and play a positive role in promoting the stable development of the fresh agricultural product supply chain, the improvement of people's quality of life, and the construction of a pleasant ecological environmental.

6. Conclusions and Outlook

6.1. Conclusions. This paper studies a three-stage fresh agricultural product supply chain system consisting of a supplier, a third-party logistics service provider (TPLSP), and a retailer, in which fresh products have no fixed shelf life, and market demand is influenced by factors such as retail price, consumer environmental protection awareness, freshness preference, and green trust level. Comparative analysis of the optimal decision-making, profits of each enterprise under decentralized decision-making without the application of blockchain technology, decentralized decision-making with blockchain technology, and centralized decision-making with blockchain technology. Analysis of the influence of factors such as consumers' environmental protection awareness, freshness preference, green trust level, blockchain technology application cost, and sharing ratio on the decision-making and profits of the supply chain system. Also, the coordination effect of the contract of "revenue sharing + double cost sharing" and the contract of "two-part tariff + revenue sharing + double cost sharing" on the three-stage supply chain system are discussed. Finally, the correctness of the theoretical model and the feasibility of the coordination contract are verified through the simulation analysis of an example. The research conclusions of this paper mainly include the following theories:

(1) Optimal wholesale price, retail price, service price, optimal carbon emission reduction level, fresh-keeping effort level, and the profits of each participant are positively correlated with consumer green trust level when blockchain technology is not applied. Although the application of blockchain technology will increase the cost of enterprises, it will also reduce transaction costs and make consumer green trust level to 1, thereby increasing the market demand. Therefore, the profits of each participant of the supply chain have been improved.

(2) When the blockchain technology application cost-sharing ratio by the supplier and the retailer is high, the wholesale price, service price, and retail price will be lower than the optimal price when blockchain technology is not applied. And, wholesale price and service price will decrease with the increase of blockchain technology application costs. Therefore, TPLSP should take the initiative to increase the sharing ratio to maximize the profits of each participant.

(3) In any decision-making mode, the decision-making and profits of each participant in the supply chain will increase with the improvement of consumer environmental protection awareness and freshness preference and decrease with the increase of carbon emission reduction cost and fresh-keeping cost. When consumers' environmental protection awareness and freshness preference are high, the unit retail price of fresh product is the highest under the decentralized decision-making when applying blockchain technology. In the centralized decision-making mode, the retailer will reduce retail price and expand market demand for the total profits of the supply chain, so the total profits of the system will be higher.

(4) Only through the contract coordination of "revenue sharing + double cost sharing" will the profit of the TPLSP reduce. When the parameters are controlled within a reasonable threshold range, the contract coordination mechanism of "two-part tariff + revenue sharing + double cost sharing" can ensure that the unit retail price, carbon emission reduction level, and fresh-keeping effort level are consistent with the optimal results of centralized decision-making and realize the Pareto improvement of the economic benefits of each participant in the supply chain.

6.2. Outlook. At present, this study still has some limitations. First of all, this paper only considers low carbon and blockchain technology as a background and does not delve into the specific measures of carbon emission reduction and the investment method of blockchain technology. Secondly, this paper only studies the supply chain of fresh agricultural products with a single offline channel and lacks market competition factors that consider online channels. Finally, this paper does not consider the government's regulatory mechanism for applying blockchain technology to the supply chain of fresh agricultural products and making decisions on carbon emission reduction and freshness-keeping [51]. Therefore, future research can explore specific measures to reduce carbon emissions in the supply chain of fresh agricultural products from the perspective of carbon cap and trade and can explore the dynamic investment decision of fresh agricultural product supply chain applying blockchain technology from the perspective of the multi-subject game [52] and also can combine online and offline channels from the perspective of government supervision, then comprehensively consider the market environment of fresh agricultural products, so as to provide more comprehensive solutions for the sustainable development of enterprises [53].

Appendix

Proof of Theorem 1. According to the converse solution method, first, find the partial derivative with respect to p^n of the retailer's profit function, order $\partial\pi_s^n/\partial p^n = 0$ can be obtained: $p^n = (\alpha + \lambda\gamma\theta + \lambda k\beta + \omega)/2$. Substitute it into equation (2) to get the supplier's profit function: $\pi_g^n = [(\omega - c - f)(\alpha - \omega + \lambda\gamma\theta + \lambda k\beta)]/2$. Then, taking the partial derivative of the supplier's profit function with respect to ω^n, order $\partial\pi_g^n/\partial\omega^n = 0$ can be obtained: $\omega^n = (\alpha + c + f + \lambda\gamma\theta + \lambda k\beta)/2$. Substituting p^n and ω^n into equation (3), the Hessian matrix of π_t^n with respect to f^n, θ^n, and β^n can be obtained:

$$H^n = \begin{bmatrix} \dfrac{\partial^2\pi_t^n}{\partial\theta^2} & \dfrac{\partial^2\pi_t^n}{\partial\theta\partial\beta} & \dfrac{\partial^2\pi_t^n}{\partial\theta\partial f} \\ \dfrac{\partial^2\pi_t^n}{\partial\beta\partial\theta} & \dfrac{\partial^2\pi_t^n}{\partial\beta^2} & \dfrac{\partial^2\pi_t^n}{\partial\beta\partial f} \\ \dfrac{\partial^2\pi_t^n}{\partial f\partial\theta} & \dfrac{\partial^2\pi_t^n}{\partial f\partial\beta} & \dfrac{\partial^2\pi_t^n}{\partial f^2} \end{bmatrix} = \begin{bmatrix} -h & 0 & \dfrac{\lambda\gamma}{4} \\ 0 & -b & \dfrac{\lambda k}{4} \\ \dfrac{\lambda\gamma}{4} & \dfrac{\lambda k}{4} & -\dfrac{1}{2} \end{bmatrix}. \quad (A.1)$$

It can be known from the Hessian matrix that when $\lambda^2hk^2 + \lambda^2b\gamma^2 - 8hb < 0$, π_t^n has a unique optimal solution. Find the partial derivatives of π_t^n with respect to f^n, θ^n, and β^n and set them to 0 to obtain f^{n*}, θ^{n*}, and β^{n*}. Substituting equations f^{n*}, θ^{n*}, and β^{n*} into equations p^n and ω^n and can be obtained ω^{n*} and p^{n*}. The optimal profits of the retailer, the supplier, and the TPLSP can be obtained from the above-given formulas.

Proof of Theorem 2. Same as Theorem 1, according to the converse solution method, order $\partial\pi_s^o/\partial p^o = 0$ can be obtained p^o, order $\partial\pi_g^o/\partial\omega^o = 0$ can be obtained ω^o, and substitute it into equation (7), the Hessian matrix of π_t^o with respect to f^o, θ^o, and β^o can be obtained:

$$H^o = \begin{bmatrix} \frac{\partial^2 \pi_t^o}{\partial \theta^2} & \frac{\partial^2 \pi_t^o}{\partial \theta \partial \beta} & \frac{\partial^2 \pi_t^o}{\partial \theta \partial f} \\ \frac{\partial^2 \pi_t^o}{\partial \beta \partial \theta} & \frac{\partial^2 \pi_t^o}{\partial \beta^2} & \frac{\partial^2 \pi_t^o}{\partial \beta \partial f} \\ \frac{\partial^2 \pi_t^o}{\partial f \partial \theta} & \frac{\partial^2 \pi_t^o}{\partial f \partial \beta} & \frac{\partial^2 \pi_t^o}{\partial f^2} \end{bmatrix} = \begin{bmatrix} -h & 0 & \frac{\gamma}{4} \\ 0 & -b & \frac{k}{4} \\ \frac{\gamma}{4} & \frac{k}{4} & -\frac{1}{2} \end{bmatrix}. \quad \text{(A.2)}$$

It can be known from the Hessian matrix that when $hb > 0$ and $(hk^2 + b\gamma^2 - 8hb)/16 < 0$, π_t^o has a unique optimal solution. Find the partial derivatives of π_t^o with respect to f^o, θ^o, and β^o and set them to 0 to obtain f^{o*}, θ^{o*}, β^{o*}, ω^{o*}, and p^{o*}. The optimal profit of the retailer, the supplier, and the TPLSP can be obtained from the above-given formulas.

Proof of Lemma 1. From the previous assumptions and the results of the Hessian matrix, it can be known that $0 < \lambda^2 (hk^2 + b\gamma^2) - 8hb < hk^2 + b\gamma^2 - 8hb$, $(\alpha + 3c_2 - c - c_1) > (a - c)\lambda > 0$, and $hk^2 - hb + b\gamma^2 < 0$. Therefore, in any case, $\theta^{o*} - \theta^{n*} > 0$, $\beta^{o*} - \beta^{n*} > 0$, $p^{o*} \geq p^{n*}$, $\pi_s^{o*} - \pi_s^{n*} > 0$, $\pi_g^{o*} - \pi_g^{n*} > 0$, and $\pi_t^{o*} - \pi_t^{n*} > 0$.

When $c_1 [(1 - 2\delta)(hk^2 + b\gamma^2) + 4(4\delta - 1)hb] - c_2 (hk^2 + b\gamma^2 + 4hb) < 0$, $f^{o*} - f^{n*} > 0$; when $[c_1 (1 - \delta) + c - 2c_2 - c\lambda^2](hk^2 + b\gamma^2) - 2hb(c_1 - 4\delta c_1 + 2c + c_2) < 0$, $\omega^{o*} - \omega^{n*} > 0$; when $(c_1 - c\lambda^2)(hk^2 + b\gamma^2) + (c - 3c_2)(hk^2 + b\gamma^2 - hb) - hb(c + c_1) < 0$, $p^{o*} - p^{n*} > 0$. In summary, the conclusion of Lemma 1 can be drawn.

Proof of Theorem 3. First, the Hessian matrix of π^z can be obtained about θ^{z*}, β^{z*}, and p^{z*}:

$$H^z = \begin{bmatrix} \frac{\partial^2 \pi^z}{\partial \theta^2} & \frac{\partial^2 \pi^z}{\partial \theta \partial \beta} & \frac{\partial^2 \pi^z}{\partial \theta \partial p} \\ \frac{\partial^2 \pi^z}{\partial \beta \partial \theta} & \frac{\partial^2 \pi^z}{\partial \beta^2} & \frac{\partial^2 \pi^z}{\partial \beta \partial p} \\ \frac{\partial^2 \pi^z}{\partial p \partial \theta} & \frac{\partial^2 \pi^z}{\partial p \partial \beta} & \frac{\partial^2 \pi^z}{\partial p^2} \end{bmatrix} = \begin{bmatrix} -h & 0 & \gamma \\ 0 & -b & k \\ \gamma & k & -2 \end{bmatrix}. \quad \text{(A.3)}$$

It can be known from the Hessian matrix that there is a unique optimal solution for π^z when $hb > 0$, $\lambda^2 hk^2 + \lambda^2 b\gamma^2 - 2hb < 0$. Find the partial derivatives of θ^z, β^z, and p^z, with respect to π^z, and set them to 0 to obtain θ^{z*}, β^{z*}, p^{z*}, and π^{z*}.

Proof of Lemma 2. From the previous assumptions and the results of the Hessian matrix, it can be known that $0 < \lambda^2 (hk^2 + b\gamma^2) - 8hb < hk^2 + b\gamma^2 - 8hb$, $(\alpha + 3c_2 - c - c_1) > (a - c)\lambda > 0$, and $hk^2 - hb + b\gamma^2 < 0$. Therefore, in any case, $p^{z*} - p^{o*} < 0$, $\theta^{z*} - \theta^{o*} > 0$, $\beta^{z*} - \beta^{o*} > 0$, and $\pi^{z*} - \pi_s^{o*} - \pi_g^{o*} - \pi_t^{o*} > 0$. In summary, the conclusion of Lemma 2 can be drawn.

Proof of Lemma 3. From the previous assumptions and the results of the Hessian matrix, it can be known that $\alpha + 3c_2 - c - c_1 > 0$, $hk^2 + b\gamma^2 - 8hb < 0$, and $hk^2 + b\gamma^2 - 2hb < 0$. Therefore, it can be concluded that $\{\partial\theta^{o/z*}/\partial c$, $\partial\theta^{o/z*}/\partial c_1$, $\partial\theta^{o/z*}/\partial h$, $\partial\theta^{o/z*}/\partial b$, $\partial\beta^{o/z*}/\partial c$, $\partial\beta^{o/z*}/\partial c_1$, $\partial\beta^{o/z*}/\partial h$, $\partial\beta^{o/z*}/\partial b$, $\partial\pi_{s/g/t}^{o*}/\partial c$, $\partial\pi_{s/g/t}^{o*}/\partial c_1$, $\partial\pi_{s/g/t}^{o*}/\partial h$, $\partial\pi_{s/g/t}^{o*}/\partial b$, $\partial\pi^{z*}/\partial c$, $\partial\pi^{z*}/\partial c_1$, $\partial\pi^{z*}/\partial h$, $\partial\pi^{z*}/\partial b$, $\partial p^{o/z*}/\partial h$, $\partial p^{o/z*}/\partial b$, $\partial p^{o/z*}/\partial c_2$, $\partial f/\omega^{o*}/\partial h$, $\partial f/\omega^{o*}/\partial h$, $\partial f/\omega^{o*}/\partial b\}$ <0; $\{\partial\theta^{o/z*}/\partial c_2$, $\partial\theta^{o/z*}/\partial\gamma$, $\partial\theta^{o/z*}/\partial k$, $\partial\beta^{o/z*}/\partial c_2$, $\partial\beta^{o/z*}/\partial\gamma$, $\partial\beta^{o/z*}/\partial k$, $\partial\pi_{s/g/t}^{o*}/\partial c_2$, $\partial\pi_{s/g/t}^{o*}/\partial\gamma$, $\partial\pi_{s/g/t}^{o*}/\partial k$, $\partial\pi^{z*}/\partial c_2$, $\partial\pi^{z*}/\partial\gamma$, $\partial\pi^{z*}/\partial k$, $\partial p^{o/z*}/\partial\gamma$, $\partial p^{o/z*}/\partial k$, $\partial p^{o/z*}/\partial c$, $\partial p^{o/z*}/\partial c_1$, $\partial f/\omega^{o*}/\partial c_2$, $\partial f/\omega^{o*}/\partial\gamma$, and $\partial f/\omega^{o*}/\partial k\}$ >0. When $\delta > hk^2 + b\gamma^2 - 4hb/hk^2 + b\gamma^2 - 16hb$, $\partial f^{o*}/\partial c_1 > 0$. When $\delta > hk^2 + b\gamma^2 - 2hb/hk^2 + b\gamma^2 - 8hb$, $\partial\omega^{o*}/\partial c_1 < 0$. In summary, the conclusion of Lemma 3 can be drawn.

Proof of Theorem 4. According to the converse solution method, let the partial derivative of π_s^d with respect to p^d be 0 to obtain p^d, substitute it into equation (12) to obtain ω^d in the same way, and then substitute ω^d into p^d to obtain p^{d1}. If the contract can achieve effective coordination, the optimal unit retail price of fresh product, carbon emission reduction level, and fresh-keeping effort level under the contract coordination should be equal to the optimal result of centralized decision-making, therefore $p^{d*} = p^{z*}$, $\theta^{d*} = \theta^{z*}$, and $\beta^{d*} = \beta^{z*}$. Let $p^{d1} = p^{z*}$, it can be obtained f^{d*}. Substitute θ^{d*}, β^{d*}, and f^{d*} into ω^d to get ω^{d*}. Then, substituting the above formulas into formulas (11)–(13), the optimal profits of retailer, supplier, and TPLSP can be obtained.

Proof of Lemma 4. Adding formulas (16)–(18) can get $\pi_s^{d*} + \pi_g^{d*} + \pi_t^{d*} = \pi^{z*}$; from the previous assumptions and the results of the Hessian matrix, it can be known that $\alpha + 3c_2 - c - c_1 > 0$, $hk^2 + b\gamma^2 - 2hb < 0$, and $0 \leq \varphi, \eta \leq 1$. If the contract can achieve effective coordination, it should satisfy that the optimal profits of each subject under contract coordination are greater than the optimal profits of decentralized decision-making. Therefore, the thresholds for φ and η at $\pi_s^{d*} - \pi_s^{o*} > 0$ are $0 < \varphi \leq \varphi_1$, $0 < \eta \leq 1$, or $\varphi_1 < \varphi < \varphi_2$; the thresholds for φ and η at $\pi_g^{d*} - \pi_g^{o*} > 0$ are $0 < \varphi < 1$ and $0 < \eta < 1$; the thresholds for φ and η at $\pi_t^{d*} - \pi_t^{o*} > 0$ do not exist; that is, when $0 \leq \varphi, \eta \leq 1$, $\pi_t^{d*} > \pi_t^{o*}$ cannot be obtained.

Proof of Lemma 5. It can be obtained by calculation that when $\pi_s^{d*} - T_1 - \pi_s^{o*} > 0$, the thresholds of φ, η, T_1, and T_2 are $0 < \varphi \leq \varphi_1$, $0 < \eta \leq 1$, $0 < T_1 < T_{11}$ or $\varphi_1 < \varphi < \varphi_2$, $0 < \eta < \eta_1$, and $0 < T_1 < T_{11}$; when $\pi_g^{d*} - T_2 - \pi_g^{o*} > 0$, the thresholds for φ, η, T_1, and T_2 are $0 < \varphi < 1$, $0 < \eta < 1$, and $0 < T_2 < T_{21}$; when $\pi_t^{d*} + T_1 + T_2 - \pi_t^{o*} > 0$, the thresholds for φ, η, T_1, and T_2 are $0 < \varphi < 1$, $0 < \eta < 1$ and $0 < T_1 < T_{12}$, $T_2 > T_{22}$ or $T_1 > T_{12}$, and $T_2 > 0$. Combining all the conditions gives the result of Lemma 5 immediately.

Data Availability

No data were available for this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Supply Chain Resilience of Mineral Resources Industry in China

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Improving the supply chain resilience of the mineral resources industry is crucial for ensuring national economic security in China. Based on the supply and demand data of China's mineral resources industry from 2002 to 2018, this study adopts system dynamics model to simulate the supply chain resilience of the mineral resources industry, the mining industry, and the smelting and processing industry under the scenario of steady economic development and the scenario of supply chain crisis. From the simulation results, the reserves of the mineral resources industry and the smelting and processing industry under the two scenarios are nearly the same, indicating that they are weakly affected by the foreign market, and both have strong resilience. The mining industry has a high dependence on imports and a lack of supply chain resilience. Under the condition of steady economic development, the output of the mining industry needs to develop at a low speed to reduce production capacity. More attention should be paid to the high level of import dependence and insufficient supply chain resilience of the mining industry. In the stable international trade situation, reserves of important minerals should be increased to alleviate the resource shortage during the supply chain crisis.

1. Introduction

The mineral resources industry provides basic material and energy security for human beings, and supports the prosperity and development of the world economy and society. China is a major producer and consumer of mineral resources in the world, and has an important influence on the world mining market. In the long run, China's demand for mineral resources will remain at a high level. However, in recent years, factors such as the continuous recurrence of the COVID-19, the slowdown of global economic growth and geopolitical conflicts have increased the uncertainty of the development of the global mineral resources industry, and the supply of China's mineral resources industry has also been affected. Therefore, it is particularly important to improve the supply chain resilience and ensure the timely supply of mineral resources [1].

Reserve is a basic strategy for building supply chain resilience, which can solve the unexpected events of supply interruption or surge in demand [2]. Mineral resources reserves can cope with economic, political, and natural emergencies, ensure steady economic development, and prevent the interruption of mineral resources supply. China also pays more and more attention to mineral resources reserve. In the mineral resources planning, China has formulated the mineral resources reserve system in detail, which lays a good foundation for improving the supply chain resilience of the mineral resources industry. However, it is rarely considered in the relevant literature to study the supply chain resilience of mineral resources industry through the change of reserves. We should further study the supply chain resilience on the basis of establishing a model to analyze mineral resources reserves.

Based on the availability of data and the comprehensiveness of the analysis, the data of the mineral resources industry from 2002 to 2018 are used, and a system dynamics model (SD: system dynamics) is employed to simulate the interrelationship of import, supply, and reserve of mineral resources industry, mining industry, and smelting and processing industry.

The following are the two main contributions of this study: (1) In terms of research content, on the basis of the simulation of reserves, the supply chain resilience of mineral resources industry, mining industry, and smelting and processing industry is compared and analyzed, so that the analysis of supply chain resilience of the mineral resources industry is more comprehensive. (2) In terms of research perspective, the mineral resource reserves are closely related to supply chain resilience. Through the simulation of the reserve scale, the analysis of the supply chain resilience can better serve the management of the mineral resource industry supply chain.

2. Survey on Related Work

The mineral resources industry is an industrial system consisting of economic activities related to the mineral resources mining, smelting, and processing. The supply chain resilience of the mineral resources industry refers to the ability of the downstream industry to recover its original state when the upstream suppliers face emergencies in the mineral resources industry.

Recent research that focused on supply chain resilience and mineral resource reserves are as follows:

First is research on supply chain resilience, which is often associated with supply chain risk management [3] and supply inventory management [4]. The research contents mainly include: the measurement of supply chain resilience [5], the scale of supply chain resilience [6], and more results focus on the analysis of driving factors of supply chain resilience [7, 8]. The research on certain industrial supply chain resilience has mainly focused on improving the resilience of the industrial supply chain [9] and the analysis of influencing factors [10]. There are few research results on the supply chain resilience of the mineral resources industry. The main results in this area include the mineral economic implications related to the supply chain and the supply chain resilience [11], and an assessment model for oil and gas supply chain resilience [12]. In studies on the supply chain resilience of the mineral resources industry, more emphasis has been placed on improving the resilience under various risks.

Second is research on mineral resource reserves. The US and Japan were the first to establish mineral resource reserves [13]. The research content of mineral resources reserve mainly covers the mineral resource reserve management [14] and the reserve scale [15]. Calculations of the reserve scale of mineral resources focus on different kinds of ores. The optimal reserves of oil and gas [16] and copper ore [17] are calculated through the actual reserves and the demand for mineral products.

The list of classifications of the literature is addressed in Table 1, which are extracted based on supply chain resilience and mineral resource reserves. In general, research results on supply chain resilience, supply chain resilience of mineral resources industry, and mineral resources reserves are abundant, but there are not enough results to further analyze supply chain resilience through the scale of mineral resources reserves. The existing studies tend to analyze the reserves and supply chain resilience of a certain type of minerals and rarely focus on the overall and the industrial heterogeneity of mineral resources industry. By simulating the supply chain resilience of mineral resources industry, mining industry, and smelting and processing industry, the results can provide a scientific basis for the sustainable development of China's mineral resources industry, and also provide a more accurate basis for the formulation of supply and reserve policies of mineral resources industry.

3. Problem Description

Mineral resources reserves can reduce the possibility of interruption of mineral resources supply chain, but large-scale reserves cannot be equated with strong supply chain resilience. In order to solve this problem, we use system dynamics model to establish supply, demand, and reserve system, and explore the supply chain resilience of mineral resources industry by analyzing reserves.

3.1. System Analysis and Data Sources. The supply chain resilience of China's mineral resources industry is studied using system dynamics (SD) model. The supply chain and demand chain of mineral resources industry are closely related to mineral resources reserves, so it is necessary to construct three subsystems to simulate the relationship among them, focusing on imports, supply, and reserves, and then analyzing the supply chain resilience. From a macro perspective, the supply of the mineral resources industry includes imports and domestic supply. The demand includes exports and domestic demand. The reserves are regulated according to supply and demand (Figure 1). For imports, set two scenarios: steady economic development and supply chain crisis. When the upstream import industry changes, the supply chain recovery capacity is further analyzed according to the changes of mineral resources industry supply and reserve.

Since the data of mineral resources industry is more comprehensive after 2002, the output value, total input, import, and export from 2002 to 2018 are used for model analysis. The output value is used to represent the domestic supply and the total input is used to represent the domestic demand. The total output value data is from the "China Industrial Statistical Yearbook." For the year with missing data, we refer to the sales output value. The total input, import, and export are mainly from the input-output table from 2002 to 2017 published by the National Bureau of statistics. For years with missing data, use the GDP growth rate to estimate the demand growth rate, and use the mineral resource industry import and export growth rate to estimate the import and export volume.

Based on the available mineral resources industry-related information and the National Mineral Resources Plan (2021–2025), the time boundary of the model simulation is set as 2002–2035. Due to the limitation of data, the

TABLE 1: Survey of supply chain resilience and mineral resource reserves.

References	Methodology	Strategy	Research focus	Industry
[4]	Hybrid fuzzy and data-driven robust optimization	Vendor-managed inventory	Supply inventory management	Health care
[5]	A systematic literature review	Three resilience dimensions analysis	Measurement of supply chain resilience	—
[6]	Partial least squares-based structural equation modelling	Three dimensions analysis	Scale of supply chain resilience	Global supply chains
[7]	Total interpretive structural modelling	Test the proposed methodology	Driving factors of supply chain resilience	COVID-19
[8]	AHP and fuzzy	Consider the drivers of the resilience and vulnerability	Driving factors of supply chain resilience	E-commerce
[9]	Quality function deployment	Identify the major risks and vulnerability factors	Improving supply chain resilience	Agricultural food
[10]	Fuzzy cognitive maps	Analyze the domino effect	Driving factors of supply chain resilience	Fashion
[11]	Evaluation of extraction and processing parameters	Discuss mineral economic implications relevant to coltan supply	Mineral economic implications related to the supply chain	Tantalum
[12]	—	Provide a holistic complex system governance	Supply chain resilience assessment	Oil and gas
[14]	GIS remote sensing technology	Builds a resource reserve management information system	Mineral resource reserve system	Mineral resources
[15]	—	Analyze many ways to increase the scale of reserves	Mineral resource reserve scale	Copper
[16]	Reserves assessment and resource optimization	Discovery of resource rich areas	Optimal reserve	Oil and gas
[17]	—	Estimate future ore reserves and energy consumption	Optimal reserve	Copper ore
Present study	SD	Analysis of supply chain resilience by simulating mineral resource reserves	Supply chain resilience	Mineral resources

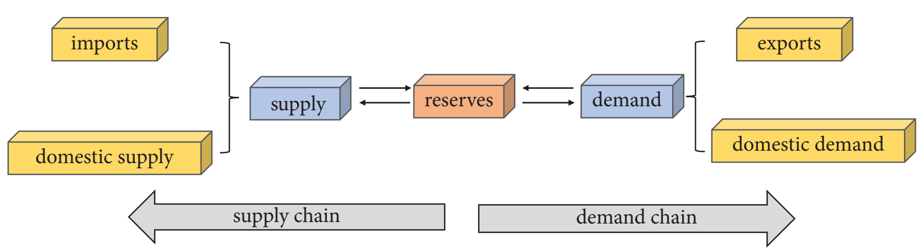

FIGURE 1: Relationship between supply chain, demand chain, and reserve of mineral resources industry.

simulation history period is 2002–2018, and the model forecast period is 2019–2035. The simulation time step is set to 1 year. The spatial boundary of the model is 30 provinces of China (excluding Hong Kong, Macao, Taiwan, and Tibet).

3.2. Model Assumptions. Based on the analysis of the relationship between supply, demand, and reserves of the mineral resources industry, and in order to facilitate the analysis of supply chain resilience by simulating the mineral resources reserve situation, the model needs to be simplified by making the following assumptions.

(1) Considering the comparability and availability of data, the import and output value of the mineral resources industry can adequately represent the supply of the mineral resources industry. Furthermore, the reserve amount can effectively measure the overall reserve of the mineral resources industry.

(2) The initial year of the model is 2002, and the mineral resources is reserved according to the goal of meeting the demand of three months

(3) The amount of mineral resources reserve is mainly influenced by the amount of supply and demand, when the two are basically balanced, no reserve is made; when the amount of supply is much larger than the amount of demand, reserve is made; when the amount of supply is much smaller than the amount of reserve, the reserve bank is released.

3.3. Model Construction. An SD model is used to simulate the reserve scale in the next 20 years according to the historical data, and the supply chain resilience of mineral resources industry is analyzed by setting two scenarios: steady economic development and supply chain crisis. Due to the wide variety of minerals and the large difference in reserves and prices of mineral resources, the reserve amount is selected to describe the reserve of mineral resources. The total demand and total supply of mineral resources industry are both measured by price. Total demand includes domestic demand and export, and total supply includes output and import.

Based on the relationship between the supply, demand, and reserves of the mineral resources industry, VENSIM PLE software was used to construct an SD model of the mineral resources industry supply chain resilience. The specific flow diagram is shown in Figure 2.

3.4. Model Structure. The system flow diagram contains three subsystems (the mineral resources industry supply chain subsystem, demand chain subsystem, and reserve subsystem), with a total of 19 variables. 5 are horizontal variables (import value, output value, export value, domestic demand value, and reserve value); 5 are rate variables(import value added, output value added, export value added, domestic demand value added and stock in amount); and the other 9 are auxiliary variables. By constructing three subsystems and establishing the relationship among them, we can better simulate the relationship among import, supply chain and reserve of mineral resources industry, laying the foundation for accurate analysis of supply chain resilience.

3.4.1. Mineral Resources Industry Supply Chain Subsystem

(1) Supply value

The supply of mineral resources industry is described by the supply value, and the annual supply value is calculated by the import value in the current year and the total output value in the current year.

$$S_t = S_{tImp} + S_{tOut}, \tag{1}$$

where S_t is the supply value of the mineral resources industry in the current year, S_{tImp} is the import value of the mineral resources industry in the current year, and S_{tOut} is the total output value of the mineral resources industry in the current year.

(2) Imports value

$$S_{tImp} = S_{(t-1)Imp} + S_{tImpadd}, \tag{2}$$

where $S_{(t-1)Imp}$ is the import value of the mineral resources industry in the previous year, and $S_{tImpadd}$ is the increase in the import value of the mineral resources industry in the current year compared with the previous year.

(3) Import value added

$$S_{tImpadd} = S_{tImp} \cdot v_{Imp}, \tag{3}$$

where v_{Imp} is the growth rate of import value of the mineral resources industry. The growth rates for the years 2012–2018 were the actual growth rates. The growth rate under different scenarios will be adopted in 2019–2035.

(4) Total output value

$$S_{tOut} = S_{(t-1)Out} + S_{tOutadd}, \tag{4}$$

where $S_{(t-1)Out}$ is the total output value of the mineral resources industry in the previous year and $S_{tOutadd}$ is the increase in the total output value of the mineral resources industry in the current year compared with the previous year.

(5) Output value added

$$S_{tOutadd} = S_{tOut} \cdot v_{Out}, \tag{5}$$

where v_{Out} is the growth rate of output value of the mineral resources industry. The growth rates for the years 2012–2018 were the actual growth rates.

3.4.2. Mineral Resources Industry Demand Chain Subsystem

(1) Demand value

The demand of the mineral resources industry is described by the demand value, and the annual demand value is calculated by the export value in the current year and the domestic demand value in the current year.

$$D_t = D_{tExp} + D_{tDem}, \tag{6}$$

where D_t is the demand value for the mineral resources industry in the current year, D_{tExp} is the export value of the mineral resources industry in the current year, and D_{tDem} is the domestic demand value of the mineral resources industry in the current year.

(2) Export value

$$D_{tExp} = D_{(t-1)Exp} + D_{tExpadd}, \tag{7}$$

where $D_{(t-1)Exp}$ is the export value of the mineral resources industry in the previous year and $D_{tExpadd}$ is the increase in the export value of the mineral resources industry in the current year compared with the previous year.

(3) Export value added

$$D_{tExpadd} = D_{tExp} \cdot v_{Exp}, \tag{8}$$

where v_{Exp} is the growth rate of export value of the mineral resources industry. The growth rates for the years 2012–2018 were the actual growth rates.

(4) Domestic demand value

$$D_{tDem} = D_{(t-1)Dem} + D_{tDemadd}, \tag{9}$$

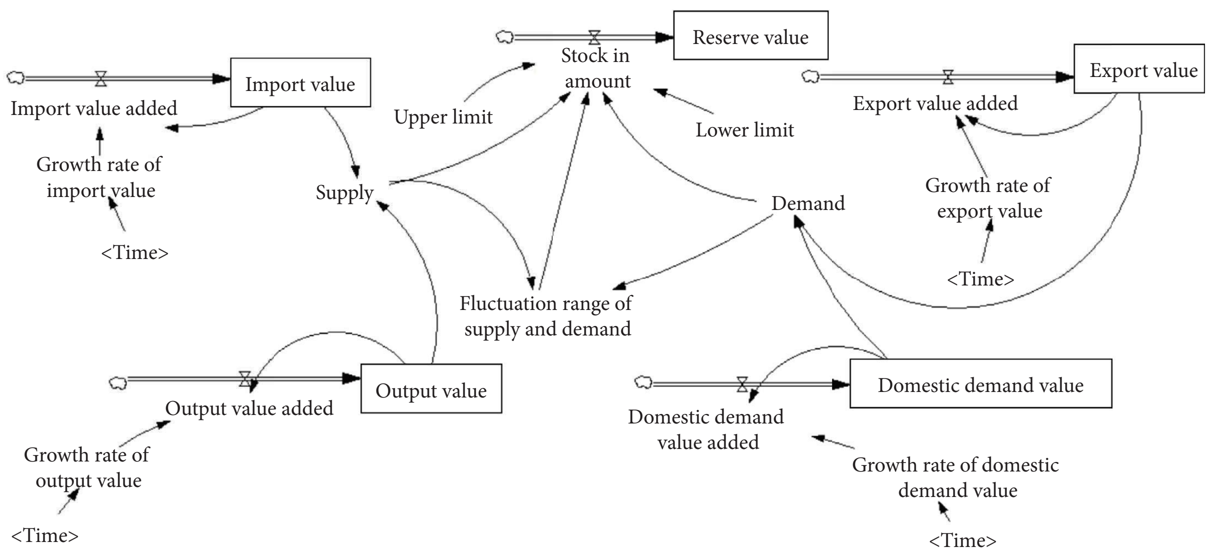

FIGURE 2: Flow chart of supply chain resilience system of mineral resources industry.

where $D_{(t-1)Dem}$ is the domestic demand value of the mineral resources industry in the previous year and $D_{tDemadd}$ is the increase in domestic demand value of the mineral resources industry in the current year compared with the previous year.

(5) Demand value added

$$D_{tDemadd}= D_{tDem} \cdot v_{Dem}, \tag{10}$$

where v_{Dem} is the growth rate of demand value of the mineral resources industry. The growth rates for the years 2012–2018 were the actual growth rates.

3.4.3. Mineral Resources Industry Reserve Subsystem

(1) Fluctuation range of supply and demand

The fluctuation range of supply and demand indicates the degree to which the supply deviates from the demand. The greater the value, the more unbalanced between supply and demand. When it exceeds a certain range, it is necessary to rely on reserves to adjust, so as to stabilize the market price and the balance between supply and demand. The calculation formula of fluctuation range of supply and demand is as follows:

$$v_t = \frac{(S_t - D_t)}{D_t}. \tag{11}$$

(2) Stock in amount

When the supply and demand are basically the same, there is no need to reserve or release mineral resources. When the supply is greater than the demand, it is necessary to reserve. When the supply is less than the demand, release of reserves is required.

$$R_t = \begin{cases} S_t-(1+\alpha)D_t, & 0 \le \alpha \le v_t, \\ 0, & \beta \le v_t \le \alpha, \\ S_t-(1+\beta)D_t, & v_t \le \beta \le 0, \end{cases} \tag{12}$$

where R_t is the reserve value of mineral resource. When $\beta \le v_t \le \alpha$, that is, the fluctuation range of supply and demand is small, and mineral resources are not reserved or released. When $0 \le \alpha \le v_t$, that is, the fluctuation range of supply and demand is greater than the upper limit, the supply is greater than the demand, and mineral resources reserve is required. When $v_t \le \beta \le 0$, that is, the fluctuation range of supply and demand is less than the lower limit, the supply is less than the demand, and mineral resources reserve need to be released to meet demand. In this study, α was set as 5% and β as −5%.

(3) Reserve value

$$M_t= M_{t-1}+R_t, \tag{13}$$

where M_t is the reserve value of the mineral resources industry and M_{t-1} is the reserve value of the mineral resources industry in the previous year.

An initial value is needed for the reserve value of mineral resource. With reference to the mineral resource reserve target of some countries, Japan has a reserve target of two months' domestic demand for some rare and other metals. In the US, the reserve target is three months' domestic demand. The initial value of mineral resource reserves in China was set as three months' domestic demand in the first year.

4. Results and Discussion

4.1. Scenarios Setting. Under the two scenarios of steady economic development and supply chain crisis, the import and reserve of mineral resources industry before 2035 are predicted according to the historical data from 2002 to 2018. If the supply chain can cope with extreme situations, there will be no significant impact on reserves, indicating that the supply chain of mineral resources industry is resilient. In order to analyze the industrial heterogeneity, that is, the difference in supply chain resilience between mining industry and smelting and processing industry, the flow chart shown in Figure 1 is also used for simulation.

The forecast period (2019–2035) in the model needed to be set up for four indicators: growth rate of imports, of exports, of output, and of domestic demand (Table 2). Under the scenario of steady development of the global economy, the mineral resources industry would have an import growth rate of 5.15% and an export growth rate of 4.54% after 2018, based on the growth rate of imports and exports in the last four to five years, excluding years with large fluctuating growth rates. According to a forecast of China's demand for major mineral resources by Wen et al. [18], the average annual growth rate of domestic demand for the mineral resources industry between 2019 and 2035 will be approximately 6.79%. The output growth rate was mainly determined based on China's GDP growth rate. The real GDP growth rates were used for 2019, 2020, and 2021 (6.1%, 2.3%, and 8.1%, respectively). From 2021 to 2035, this value is replaced by China's potential economic growth rate: 7.29% in 2021–2025, 6.97% in 2026–2030, and 6.49% in 2031–2035.

There is significant overcapacity in the mining industry, therefore, output growth rate should be reduced. According to the growth rate of output value in recent years, it is set to dissolve the overcapacity at the rate of −0.0714% for five consecutive years. In order to prevent the continuous growth of production capacity, half of the average growth rate 1.875% is taken as the future development according to the growth rate of output value in recent 10 years. According to the growth rate of import value and export value in recent years, it is determined that after 2018, the growth rate of import is 7.43%, of exports is 3.44%, and of demand is 6.97%.

The supply and demand of smelting and processing industry accounts for about 70% of the mineral resources industry. The growth rates of imports, exports, output, and domestic demand of smelting and processing industry were determined in the same method as for the mineral resources industry. The import growth rate is 5.7%, export growth rate is 4.78%, and the domestic demand and output growth rates are the same as those for the mineral resources industry.

Due to the changeable international situation, it is assumed that there will be a supply chain crisis in 2025 and the import will be blocked. Referring to the existing research results [19], the decrease after a large impact is set at 50%, and the import will recover in the next year. Other parameters are consistent with the steady economic development.

4.2. Simulation Results. Figure 3 shows the import, supply, and reserve of mineral resources industry from 2002 to 2018. The import and supply show an overall rise. The import account for a relatively small proportion of the supply in mineral resources industry and smelting and processing industry, so the fluctuation in import will not have a great impact on supply. The import accounts for a very large proportion of the supply in mining industry. The stability of import will directly affect the stability of the supply chain of mining industry. The reserve is the cumulative value over the years. There has been overcapacity in the mineral resources industry and the smelting and processing industry since 2011. The supply of mining industry accounts for a relatively small proportion in the mineral resources industry, but the overcapacity is more serious.

According to the set parameters, under the condition of steady economic development and supply chain crisis scenarios (Table 3), the reserve of mineral resources industry and smelting and processing industry are the same, indicating that the supply chain crisis has basically no impact on the reserve. The supply chains of mineral resources industry and smelting and processing industry exhibit strong resilience.

By contrast, the mining industry needs to adopt a low-speed growth due to its large overcapacity. According to the set parameters, under the steady economic development scenario, with the implementation of a de-capacity policy, the reserve continues to decrease, which can meet China's demand for more than three months. Under the supply chain crisis scenario, the release of reserves would accelerate, and it is necessary to improve the growth rate of supply to meet China's demand.

4.3. Sensitivity Analysis. Sensitivity analysis is presented in a simulation. In the process, you can observe the sensitivity of A variable to B variable. In general, A can only be a constant. In this study, since the constants in the model are not the main variables, different time steps are used to analyze the sensitivity. In addition to the 1-year time step in the simulation, the simulation with 0.5-year and 0.25-year time steps are added. The sensitivity analysis of mineral resources industry, mining industry, and smelting and processing industry under different scenarios has little difference, so take the mineral resources industry under the supply chain crisis scenario as a representative to analyze the simulation results of imports and reserves under different time steps (Figure 4).

It can be seen that the sensitivity of the reserve is greater than that of the import. In addition, the sensitivity of output, export, domestic demand, and other variables is similar to that of import, and the sensitivity is low. It shows that the system is insensitive to most parameter changes, the model has good stability, and can well simulate the actual system.

4.4. Analysis of Results. According to the simulation results of import, supply, and reserve of the mineral resources industry, the supply of mineral resources industry and smelting and processing industry is weakly affected by import, whereas the supply of the mining industry is greatly influenced. After 2009, the reserves of the mineral resources increased. The reserve has far exceeded the target of three months' domestic demand, with production overcapacity. In

Table 2: Parameters under steady economic development and supply chain crisis from 2019 to 2035.

*S*1	Mineral resources industry	GR import: 5.15%. GR export: 4.54%. GR demand: 6.79%. GR output: 6.1% in 2019, 2.3% in 2020, 8.1% in 2021, 7.29% in 2022–2025, 6.97% in 2026–2030, 6.49% in 2031–2035.
	Mining industry	GR import: 7.43%. GR export: 3.44%. GR demand: 6.79%. GR output: −0.0714% in 2019–2021, 1.875% in 2022–2035.
	Smelting and processing industry	GR import: 5.70%. GR export: 4.78%. GR demand: 6.79%. GR output: 6.1% in 2019, 2.3% in 2020, 8.1% in 2021, 7.29% in 2022–2025, 6.97% in 2026–2030, 6.49% in 2031–2035.
*S*2	Mineral resources industry, mining industry, and smelting and processing industry	GR import: 2025: −50%, other years are consistent with *S*1. GR export: consistent with *S*1. GR demand: consistent with *S*1. GR output: consistent with *S*1.

Note. GR represents the growth rate, *S*1 represents the scenario 1 (steady economic development), and *S*2 represents the scenario 2 (supply chain crisis).

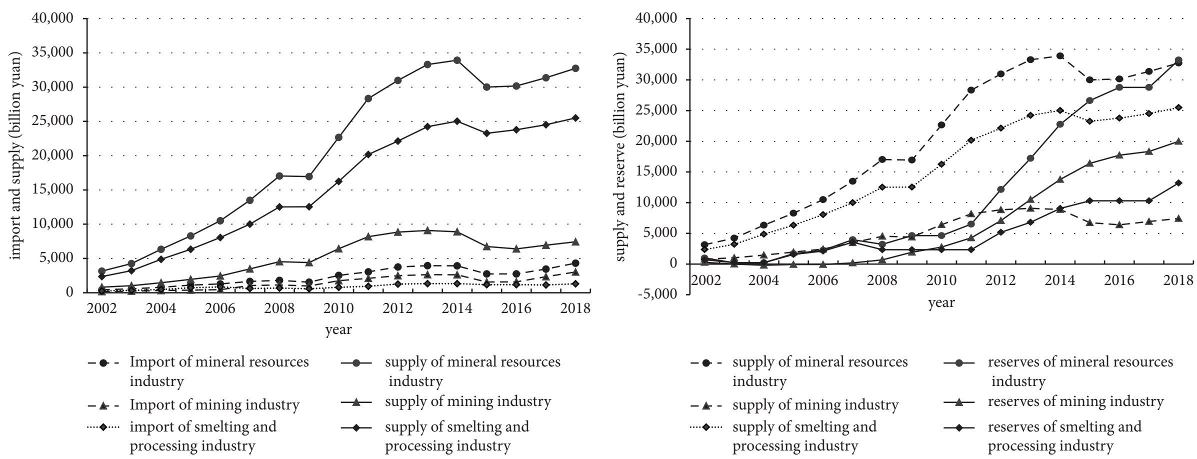

Figure 3: Changes in import, supply, and demand of mineral resources industry from 2002 to 2018.

Table 3: Model results of mineral resources industrial reserve system (trillion yuan).

Year	Import						Reserves			
	*S*1: *M*	*S*2: *M*	*S*1: *E*	*S*2: *E*	*S*1: *S*	*S*2: *S*	*S*1 and *S*2: *M*	*S*1: *E*	*S*2: *E*	*S*1 and *S*2: *S*
2019	4.53	4.53	3.24	3.24	1.37	1.37	35.79	21.82	21.82	13.2
2020	4.76	4.76	3.48	3.48	1.45	1.45	38.26	23.19	23.19	13.2
2021	5.01	5.01	3.74	3.74	1.53	1.53	38.26	24.1	24.1	13.2
2022	5.26	5.26	4.01	4.01	1.61	1.61	38.26	24.56	24.56	13.2
2023	5.54	5.54	4.31	4.31	1.71	1.71	38.26	24.56	24.56	13.2
2024	5.82	5.82	4.63	4.63	1.8	1.8	38.26	24.17	24.17	13.2
2025	6.12	2.91	4.98	2.32	0.9	0.9	38.26	23.63	23.63	13.2
2026	6.44	6.12	5.35	4.98	1.91	1.91	38.26	22.93	20.27	13.2
2027	6.77	6.44	5.74	5.35	2.02	2.02	38.26	22.06	19.03	13.2
2028	7.12	6.77	6.17	5.74	2.13	2.13	38.26	21.01	17.58	13.2
2029	7.48	7.12	6.63	6.17	2.25	2.25	38.26	19.76	15.91	13.2
2030	7.87	7.48	7.12	6.63	2.38	2.38	38.26	18.31	14	13.2
2031	8.27	7.87	7.65	7.12	2.52	2.52	38.26	16.64	11.84	13.2
2032	8.7	8.27	8.22	7.65	2.66	2.66	38.26	14.73	9.4	13.2
2033	9.15	8.7	8.83	8.22	2.81	2.81	38.26	12.57	6.68	13.2
2034	9.62	9.15	9.48	8.83	2.97	2.97	38.26	10.14	3.64	13.2
2035	10.11	9.62	10.19	9.49	3.14	3.14	38.26	7.43	0.27	13.2

*Note. S*1 represents the scenario 1, *S*2 represents the scenario 2, *M* represents the mineral resources industry, *E* represents the mining industry, and *S* represents the smelting and processing industry. The reserves of mineral resources industry and smelting and processing industry are the same under scenario 1 and scenario 2.

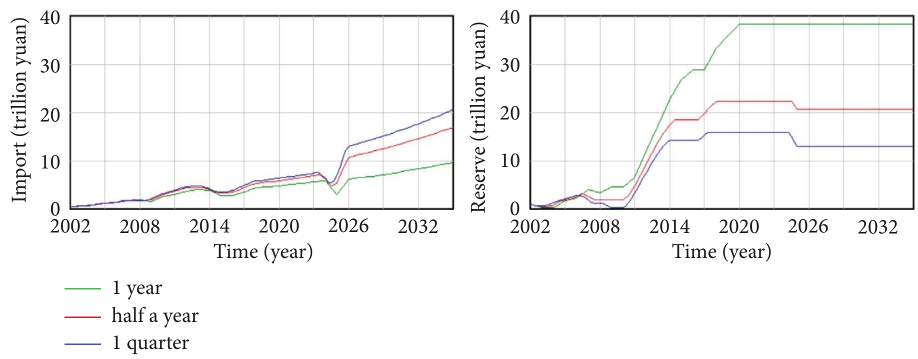

Figure 4: Sensitivity analysis of mineral resources industry under supply chain crisis.

2016, China's Ministry of Land and Resources and various provinces have gradually implemented policies to resolve the problem of overcapacity in the mineral resources industry. It is estimated that by 2035, the supply and demand of the mineral resources industry will basically be balanced, and the reserve of mineral resources will remain unchanged. Owing to the continuous growth of demand, the reserve will be able to meet the demand for more than three months, but the ratio of reserve to demand will decline year by year. If the economy continues to develop steadily, after 2035, it will be necessary to increase the supply by increasing the output or import to ensure the ratio of reserve to demand does not continue to decline.

In recent years, China's economy has developed rapidly, the output value of mineral resources is relatively stable, and the fluctuations are within a reasonable range. Imports will be mainly affected by foreign economic and political situations in China. Assuming there is a large shock (set as a 50% decline) to the import in a given year (set as 2025), our analysis indicates the results of the reserve under the two scenarios are basically the same. The reason is that from 2002 to 2018, the import accounted for a relatively small proportion of the supply, ranging from 9% to 16%. The sudden decline in import basically has no impact on the supply and reserve of the mineral resources industry in China. The supply chain of the mineral resources industry has strong resilience. In real life, there are substantial differences between mineral species in China. Only a small amount of mineral resources, such as lead-zinc ore, can be self-sufficient, and about 2/3 of the strategic minerals have more than 70% dependence on foreign countries. Overall, there is a contradiction between the large demand for imported mineral products and the strong resilience of mineral resources industry in China, which needs to be analyzed at different industry.

From the perspective of the mining industry, from 2002 to 2018, the reserve was much larger than demand. Compared with the mineral resources industry, the problem of overcapacity is more serious in mining industry. Although the output value has shown negative growth in recent years, the problem of overcapacity has not been completely solved. In the steady economic development scenario, in order to resolve the problem of overcapacity, first maintain the negative growth trend, and then set the future growth rate according to the slight rise. The results of the model show that the reserve in amount continues to decrease after 2018. From 2023, it is mainly the release of reserves. By 2035, the proportion of reserves in the demand will be 43.65%, which can meet the basic demand. Although there is overcapacity under the steady economic development, there are great differences among different minerals. For example, there are long-term shortages of domestic supplies of crude oil, natural gas, coal, iron ore, and copper concentrate. In 2019, these minerals accounted for approximately 85% of China's total imports of minerals.

When the import of mining industry is greatly impacted and decreases by 50%, the supply decreases significantly, indicating that the supply chain resilience is insufficient. From the perspective of reserve, after the impact, by 2035, the reserve would account for 23.79% of the demand, which is less than the three months' domestic demand target. It would be necessary to increase the output or import. The lack of supply chain resilience in mining industry is due to the large share of import in the supply, between 18.02%–40.19%, and shows a continuous growth trend. The larger the proportion of import in the supply, the higher the degree of control by the foreign market and the weaker the supply chain resilience. In the period of global economic stability, more strategic minerals should be stockpiled to meet domestic demand for mineral products during supply chain crises.

From the perspective of smelting and processing industry, it is basically consistent with the change trend of mineral resources industry. The total supply of the smelting and processing industry accounts for more than 70% of the mineral resources industry and continues to grow, which has a great impact on the change trend of mineral resources industry. Under the two scenarios of steady economic development and supply chain crisis, the reserve of the smelting and processing industry has not changed, and the supply chain has strong resilient.

Analysis of imports of the mining industry and smelting and processing industry reveals that China's imports of mineral resources are mainly in the mining industry, and growth of imports is accelerating. The ratio of import of mining industry to smelting and processing industry increased from 0.68 in 2002 to 2.33 in 2018. For the following reasons: first, although China is rich in mineral resources, some minerals are of low grade and difficult to mine. As the demand for mineral products continues to grow, the domestic output cannot meet the demand. Secondly, the process from discovery to mining of mineral resources is complex. The mining cost is high, so it is better to import high-grade raw ore directly. Finally, with the continuous improvement of smelting and processing technology in China, the cost can be saved by importing raw ore and domestic processing. This also explains the lack of supply chain resilience in the mining industry, while the supply chain resilience in the mineral resources industry is strong and less affected by the impact of emergencies. It is notable that the mining industry is an upstream industry of the smelting and processing industry. The lack of supply chain resilience in the former will affect the supply chain resilience of the latter. In order to ensure the supply chain security of China's mineral resources industry, it is necessary to stockpile important mineral products in time.

5. Conclusions and Managerial Insights

Based on the SD model, this paper analyzes the supply chain resilience of the mineral resources industry, mining industry, and smelting and processing industry. The research content is more comprehensive. In addition, by simulating the changes of import, supply, and reserve of mineral resources industry under the scenario of steady economic development and the scenario of supply chain crisis, and then analyzing the supply chain resilience, the research perspective is more novel, which can better serve the supply chain management of mineral resources industry.

The results of this research and managerial insights are as follows:

(1) The supply of smelting and processing industry accounts for more than 70% of the mineral resources industry. Under the two scenarios of steady economic development and supply chain crisis, the reserves of the two industries have basically not changed, and the supply chains have strong resilience.

(2) The mining industry is highly dependent on imports. During a supply chain crisis, the sharp decline of import will continuously reduce the reserves of the mining industry. It is necessary to continuously make up for the shortage of supply by increasing import or output after the crisis. Supply chain resilience is insufficient.

(3) From the relationship between the mining industry and the smelting and processing industry, the import mode of mineral resources industry has changed from directly importing a large number of mineral products after smelting and processing to mainly importing raw ores for deep processing in China. Although the results show that the supply chain resilience of the smelting and processing industry is strong, its upstream industry is dominated by the mining industry. The lack of supply chain resilience of the mining industry will affect the supply chain resilience of the smelting and processing and the mineral resources industry.

The managerial insights are as follows: in China's mineral resources reserve, the resource reserves of mining industry should be given priority attention, and the reserve of raw ores should be appropriately increased to reduce the dependence of mining industry on imports during the supply chain crisis. In order to ensure supply chain security and improve supply chain resilience, the scale of strategic mineral resources reserves should be appropriately increased. For mineral species with high import dependence, the import from one country will be changed to multi-country import to weaken resource monopoly and price monopoly.

The main limitation of the study is simulation analysis of important mineral reserves and supply chain resilience. For future studies, it is suggested to use SD model to accurately simulate the reserves and supply chain resilience of many important minerals. It is better to use exact algorithms such as Lagrange relaxation and meta-heuristic algorithms [4, 20].

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Designing Sustainable Recovery Network of End-of-Life Product during the COVID-19 Pandemic: A Real and Applied Case Study

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One of the most important aspects of supply chain management (SCM) is the recovery network (RN), which covers all activities associated with return products (such as collection, recovery, repair, recycling, and waste disposal). Our goal in this paper is to provide a new mathematical model of sustainable end-of-life management (SEOLM) during the COVID-19 pandemic for readers. The suggested recovery network model (RNM) can explain the trade-offs between economic (minimizing total costs), environmental (minimizing bad environmental impacts), and social (minimizing bad social impacts) aspects during the pandemic and the great lockdown. A new RN can be designed with a sustainable and hygienic design when taking environmental, economic, and social considerations into account. It proposes guidelines for managers and scholars on how to address recovery network design (RND) challenges during the pandemic through a mathematical article with a sustainable approach. The scalarization approach of a multi-objective mixed-integer programming (MOMIP) problem in this paper is the weighted sum method. The validation of the presented model and the related Pareto frontier has been illustrated by a case study and numerical example. To perform the optimization process, Lingo software is used.

1. Introduction

COVID-19 can be contagious very quickly [1]. Keeping physical contact low and locking down are two important prevention strategies for COVID-19 [2]. Emissions are also fundamentally affected by the growing COVID-19 outbreak [3]. Resource consumption and environmental pollution can be reduced by recovering end-of-life (EOL) products [4, 5]. RN's total cost should be kept as low as possible [6]. The recovery technique is different on several factors: type of product, backward flow, the demand of the market, status of the product, and technical conditions. Maximization of the value of recovery of EOL products is important to make a recovery decision [7]. The important purpose of the disassembly method is to revitalize EOL products by methodically separating their parts and materials for recycling, reproduction, and reuse [8]. Most manufacturing companies focus on forwarding flows and pay no attention to the backward flows. The product life cycle (LC) consists of three steps. The last step is end of life (EOL): collecting/remanufacturing/reuse/recycle/disposal [9]. COVID-19 virus life spans on different surfaces are shown in Figure 1.

We need to consider how long the coronavirus remains on different objects. Product recovery minimizes waste by recovering, recycling, and reproducing [8]. Reducing CO_2 emissions is one of the important targets of RN design [18]. During the COVID-19 crisis and the intensive lockdowns, China's CO_2 emissions decreased [19]. Keeping a virus from infecting you is the best way to prevent illness [20]. Phuluwa et al. studied the implementation of EOL options for the railcar and development of a sustainable decision framework [21]. Based on the above assumption, this has to have the specifications of the EOL product. In the reverse logistics (RLs), the returned products are collected from customers

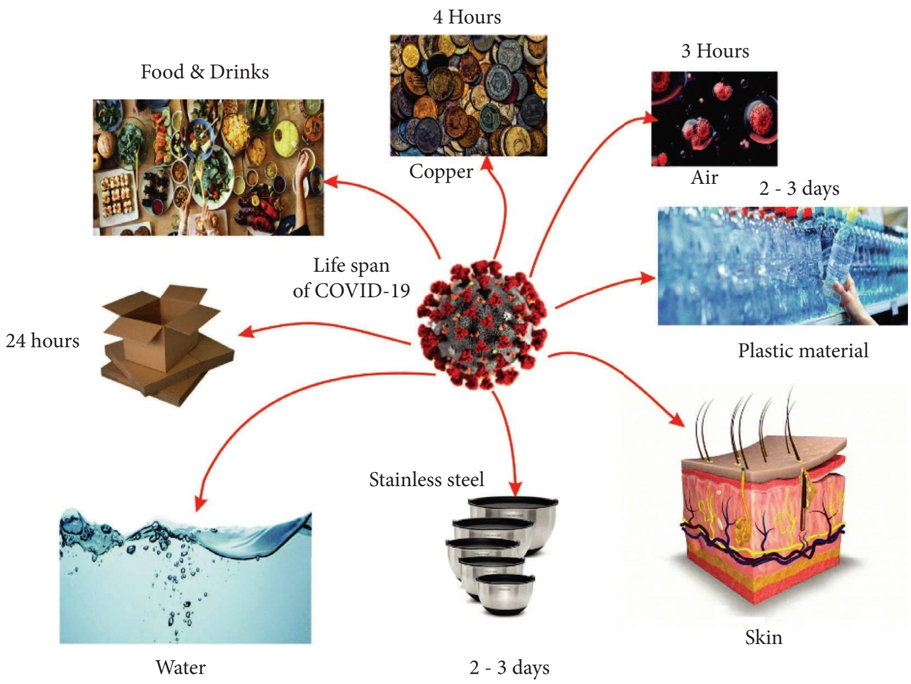

Figure 1: The life span of the COVID-19 virus on different surfaces [10–17].

and shipped to the collection centers, where the returned products are examined and classified as those that are suitable for remanufacturing/refurbishing, recovering/repairing, recycling, and the landfilling/incineration sent to the (*F*), (*P*), ($R = R_{\text{normal}}$ and $R_{\text{COVID-19}}$), and others sent to the disposal centers ($D = D_{\text{normal}}$and $D_{\text{COVID-19}}$). Quantity of the remanufacturing, refurbishing, recovering, repairing, and recycling products is consigned to the secondary market for new selling. The proposed recovery network model (RNM) can explain the trade-offs between economic, environmental, and social aspects during the pandemic and lockdown period. This paper simultaneously presents a sustainability framework's MOMIP model and COVID-19 pandemic issues.

2. Literature Review

2.1. Survey on the Related Investigation. Jun et al. [22] expressed a multi-objective optimization (MOO) for EOL product recovery. Zambrano-Monserrate et al. [23] presented multiple models for EOL management. Keivanpour et al. [24] suggested a closed-loop supply chain (CLSC) for EOL products. Ziout et al. [25] researched recovery techniques with various levels of data quality on EOL products. Remery et al. [26] solve the mathematical problem of EOL with a MIPM method. Xanthopoulos and Iakovou [27] classified EOL into six options. There are several types of research in RLs fields done by Minner [28, 29]. Bing et al. [30] designed the reverse flow of the waste of plastic with a sustainable approach. Rogetzer et al. [31] researched recycling materials with a sustainable approach. Two study sources provided a new way to predict the cost at the early stage for EOL products by specifying the best EOL option with the AHP method [32, 33]. Wilson and Goffnett [34] focus on RLs activities for EOL products considering the environment and societal issues. Gunji et al. [35] studied about optimization of the disassembly sequence for EOL products. Mamaghani and Boucher [36] investigated on recovery optimization of EOL products and considered reducing CO_2 emissions. Research on the disassembly of an EOL product considers CO_2 emission, cost of energy, and job creation [37]. Jain et al. worked on the EOL and waste management in the framework [17]. The collection method of EOL textiles and reverse logistics was studied by Gröhn [38]. Modoi and Mihai proposed the economy model between e-waste and end-of-life vehicles [39]. Hernandez-Betancur et al. [40] suggested a new approach for managing the EOL for the chemical industry. Zuidwijk and Krikke [41] focused on sustainable supply chain (SC) and RLs. Fathollahi-Fard et al. [42] investigated environmental and economic issues, designing a reverse flow for citrus fruit crates. Kaviyani-Charati et al. [43] researched SC considering environmental aspects with a mixed-integer linear programming approach. The analysis evaluated the intelligence component and greenness of Iranian ports using data envelopment analysis (DEA) by Sadri et al [44]. In a study by Daneshdoost et al. [45], they searched for a method based on hybrid meta-heuristic approaches for the minimization of cable production costs. Ghoushchi et al. [46] studied the landfill site selection problem. Fasihi et al. [47] researched RLs in the fish industry. Gautam et al. [48] investigated on circular economy approach for managing end-of-life photovoltaic e-waste in India. Rentizelas et al. [49] investigated circular economy pathways for reverse supply networks for wind turbine blades in Europe. Okumura et al. [50] proposed the model for evaluating the circularity of end-of-life products using reuse efficiency. Huang et al. [51] suggested a framework for materials flows by integrating circular economy principles and end-of-life management techniques.

Koroma et al. [52] researched on the future electricity mixes and different management strategies for end-of-life batteries while assessing the life cycle costs of battery electric vehicles. The sustainable recovery network (SRN) is considered in the following table. In Table 1, no papers have taken into address the multi-objective and COVID-19 pandemic issues simultaneously.

2.2. Research Gap and Innovation. Several research gaps exist due to the novelty of the COVID-19 pandemic. A summary of the paper can be categorized as follows: literature gaps, new assumptions, and innovations.

(1) Designing a mathematical model for production recovery considering the impacts of COVID-19 pandemic.
(2) Designing a hygienic RN during the COVID-19 outbreak.
(3) Establishing a new SRN based on sustainability in three dimensions:
    (i) Incorporating hygienic costs from COVID-19 into basic models to add economic aspects.
    (ii) Creating an assessment of the environmental benefits resulting from using recovered, remanufactured, and recycled EOL products during the COVID-19 and lockdowns.
    (iii) Developing the social dimensions of COVID-19 and lockdowns as they pertain to positive and negative consequences to society.
(4) Discussion of managerial implications to improve decision-making based on the model.

This study aims to fill this gap in the COVID-19 disaster condition by developing a new and hygienic SRN model.

3. Problem Statement and Assumptions

This research focuses on the SEOLM in RLs. This mathematical model has as its objective minimization of the COVID-19 and lockdown periods' costs, social effects, and environmental impacts on RN.

According to the mathematical model described above, seven types of facilities are available:

(1) Customers (C),
(2) Collection centers (M),
(3) Remanufacturing and refurbishing centers (F),
(4) Recovery and repair center (P),
(5) Normal and COVID-19 recycling centers (R),
(6) Normal and COVID-19 landfill and incineration centers (Disposal Centers) (D),
(7) Secondary markets (Reuse Market) (K).

Based on the above assumption, this has to have the specifications of the EOL product. In the RLs, the returned products are collected from customers and shipped to the collection centers, where the returned products are examined and classified as those that are suitable for remanufacturing/refurbishing, recovering/repairing, and recycling, sent to the (F), (P), ($R = R_{\text{normal}}$ and $R_{\text{COVID-19}}$), and others sent to the disposal centers ($D = D_{\text{normal}}$ and $D_{\text{COVID-19}}$) for landfilling and incineration. Three aspects of sustainability are discussed in this paper. Recycling reduces costs and improves economic efficiency while being environmentally friendly. This mathematical model combines economic, environmental, and social indicators in the RN during pandemics and lockdowns to increase efficiency. To create the RN, indices are used in a mathematical modeling method, and MOO is performed to complete the creation of the RN. The total cost is a measure to calculate all the monetary expenditure of the RN design. With the model, we can design RNs that best accommodate the following facilities (Customers-Collection Centers-Remanufacturing/Refurbishing Centers-Recovery/Repair Centers-Recycling Centers-Landfill/Incineration Centers-Secondary Markets) or we can distinguish product flows between the various levels. For the best network scenario, consider the total costs, the environmental and social factors related to RN activities during the COVID-19 and lockdown days. By having this information at their disposal, decision-makers (DMs) can make better, more sustainable decisions when faced with a pandemic. We describe the RND model in four subsections: problem statement and assumptions, model components, formulation process, and multiobjective mythology. The designed schematic of the problem is shown in Figure 2.

Mathematical models require several assumptions:

(1) It is supposed that a determined percentage of the returnedproducts are disposed.
(2) In the RN, the COVID-19 outbreak is thoroughly investigated.
(3) Potential areas include M, F, P, R, and D.
(4) Customers and secondary markets have fixed locations.
(5) Depending on the connection, there are different shipping options available.
(6) A feasible distance should be between network nodes.
(7) This study focuses on reverse flows.
(8) All returned product to be disposed that enters a disposal center is successfully incinerated and landfilled with hygiene protocols.
(9) Each recycling and disposal center is divided into normal and COVID-19 sections separately.
(10) All waste must be considered nonrecyclable and disposed of by incineration and sanitary landfill.
(11) Separate the infectious and noninfectious waste in the collection center.

3.1. Proposed Model. RN models include the following sets, parameters, and variables:

As the sets M, F, P, R, D, C, and K illustrate, they correspond to the potential collection centers, the potential

Table 1: Different aspects of the SRN consider the COVID-19 pandemic.

References	Considering economic aspects	Considering environmental aspects	Considering social aspects	Considering COVID-19 pandemic
[53]	*	*		
[54]	*	*		
[55]	*			
[56]	*			
[22]	*			
[57]	*			
[58]	*			
[59]	*			
[60]	*			
[61]	*	*		
[62]	*	*		
[63]	*	*		
[64]	*	*		
[65]	*			
[66, 67]	*	*		
[68]	*			
[69]	*	*	*	
[70]	*	*	*	
[47]	*			
[71]	*	*	*	
[34]	*	*	*	
[39]	*			
[40]	*	*	*	
This research	*	*	*	*

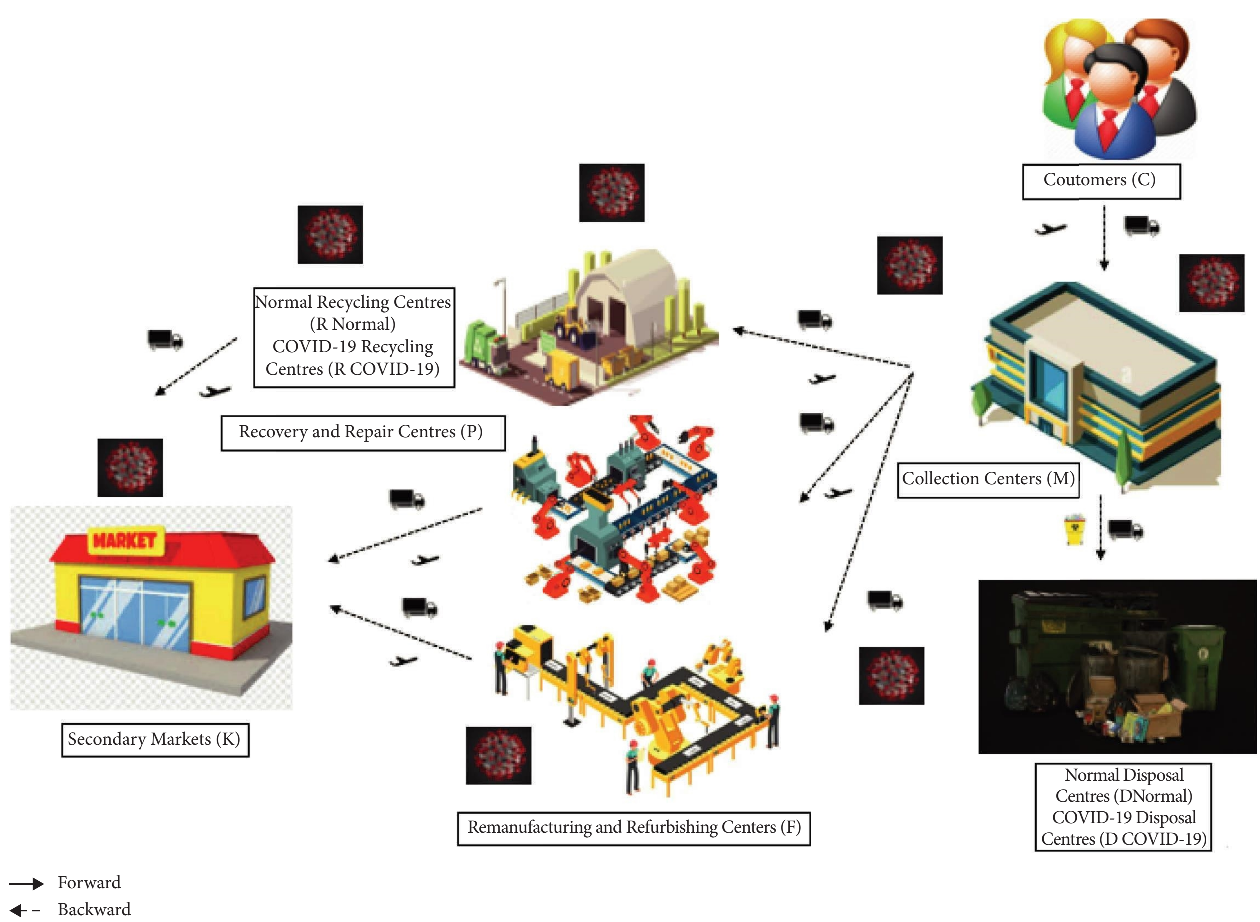

Figure 2: The RN between echelons during the COVID-19.

remanufacturing and refurbishing centers, the potential recovery and repair centers, the potential recycling centers, the potential disposal centers, the fixed customers, and the fixed secondary markets. The sets TC, TM, TF, TP, and TR include the shipping options from C, M, F, P, and R. The parameters of the model include technical, economic, environmental, and social parameters. In this model, the objective is to assign RNs to product units and determine the number of product units that flow through the network. The binary and decision variables help achieve this objective. The impacts of the COVID-19 virus on RN are shown in Figure 3 [10]. The new indicators of sustainability are shown in Table 2.

Notations:

The notations of the mathematic model were explained in this section.

Indices:

$c = \{1, 2, \ldots, C\}$: Set of fixed locations for customers.

$m = \{1, 2, \ldots, M\}$: Set of potential locations for collection centers.

$f = \{1, 2, \ldots, F\}$: Set of potential locations for remanufacturing and refurbishing centers.

$p = \{1, 2, \ldots, P\}$: Set of potential locations for recovery and repair centers.

$r = \{1, 2, \ldots, R\}$: Set of potential locations for recycling centers.

$d = \{1, 2, \ldots, D\}$: Set of potential locations for landfill and incineration centers (Disposal Centers).

$k = \{1, 2, \ldots, K\}$: Set of fixed locations for secondary markets (Reuse Market).

$tc = \{1, 2, \ldots, TC\}$: Set of shipping options from customers.

$tm = \{1, 2, \ldots, TM\}$: Set of shipping options from collection centers.

$tf = \{1, 2, \ldots, TF\}$: Set of shipping options from remanufacturing and refurbishing centers.

$tp = \{1, 2, \ldots, TP\}$: Set of shipping options from recovery and repair centers.

$tr = \{1, 2, \ldots, TR\}$: Set of shipping options from recycling centers.

Technical parameters:

Ω_c: The returned product of customer c.

CAP_m: Maximum capacity for collecting products.

CAP_f: Maximum capacity for remanufacturing and refurbishing products.

CAP_p: Maximum capacity for recovering and repairing products.

CAP_r: Maximum capacity for recycling.

CAP_d: Maximum capacity for landfilling and incinerating product.

δ_{cm}: Distance between customer c and collection center m.

δ_{mf}: Distance between collection center m and remanufacturing/refurbishing center f.

δ_{mp}: Distance between collection center m and recovery/repair center p.

δ_{mr}: Distance between collection center m and recycling center r.

δ_{md}: Distance between collection center m and disposal center d.

δ_{fk}: Distance between remanufacturing and refurbishing center f and secondary market k.

δ_{pk}: Distance between recovery/repair center p and secondary market k.

δ_{rk}: Distance between recycling center r and secondary market k.

Economic parameters:

F_m: Fixed cost for opening collection center m.

F_f: Fixed cost for opening remanufacturing/refurbishing center f.

F_p: Fixed cost for opening recovery/repairing center p.

F_r: Fixed cost for opening recycling center r.

F_d: Fixed cost for opening disposal center d.

C_m: The variable costs for collecting, inspecting, and sorting a unit of the returned and infectious/noninfectious waste in the collection center m.

C_f: The variable costs for remanufacturing and refurbishing a unit of returned product from the remanufacturing and refurbishing center f.

C_p: The variable costs for recovering and repairing a unit of returned product from the recovery/repairing center p.

C_r: The variable costs for recycling a unit of the returned product and infectious/noninfectious waste from the recycling center r.

C_d: The variable costs for landfilling and incinerating a unit of the returned product and infectious/noninfectious waste from the disposal center d.

TC_{cm}^{tc}: The unit shipping cost of the returned product and infectious/noninfectious waste sent from customer c to collection center m with shipping option tc.

TC_{mf}^{tm}: The unit shipping cost of the returned product is available for remanufacturing/refurbishing from collection center m to remanufacturing and refurbishing center f with shipping option tm.

TC_{mp}^{tm}: The unit shipping cost of the returned product is available for recovering and repairing from collection center m to recovery/repair center p with shipping option tm.

TC_{mr}^{tm}: The unit shipping cost of the returned product and infectious/noninfectious waste is available for recycling from collection center m to recycling center r with shipping option tm.

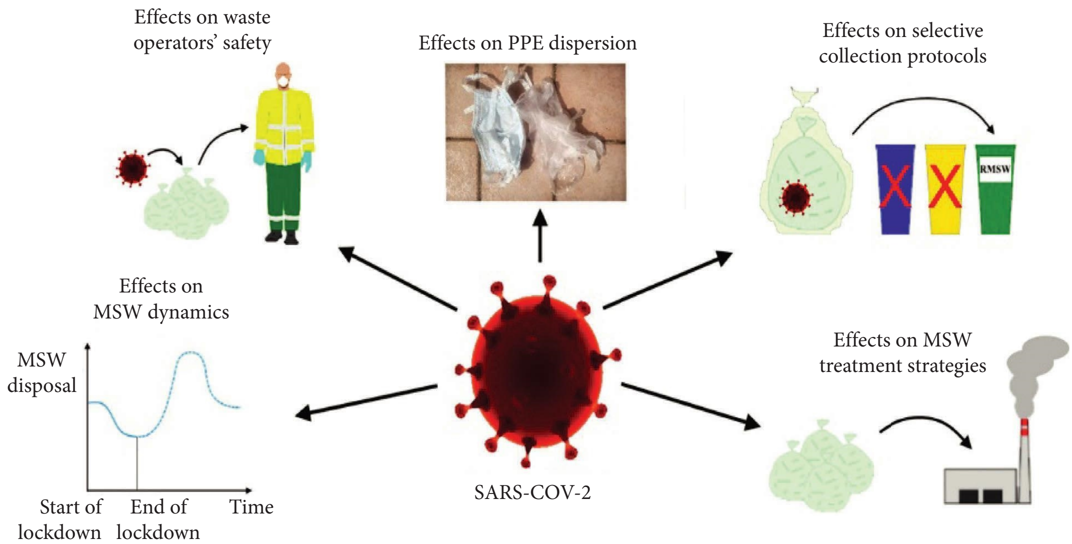

Figure 3: Effects of COVID-19 virus on RN.

Table 2: The indicators of sustainability for SRN during the COVID-19.

Indicator	Descriptions	Reference
Hygienic costs	Costs associated with preparing PPE for RN employees (shield, mask, gown, gloves, etc.). Costs associated with COVID-19 tests for RN employees. RN employees' education costs for preventing and controlling COVID-19. RN employees' medicines, vaccine, and vaccination costs. The cost of separating the infectious and noninfectious waste. The cost of disinfections and sanitizations in RN.	[72]
Positive effects of COVID-19 on environment	Reducing hazard gas emissions and recovery and industrial activities. Reducing hazard gas emissions and shipping activities. Minimizing noise pollution. Reduction of pressure on tourist destinations to restore the environment. Plant and animal species are protected. Development of IT parks, research centers, and consultancy related to COVID-19 prevention and control. Improved scientific and technological discoveries (medical advancement)	[55, 73–75]
Negative effects of COVID-19 on environment	Increase medical waste. Increasing the disposal of PPE waste (the pollution of soil and water caused by plastic waste). Growing infectious waste.	[23, 76, 77]
Positive effects of COVID-19 on social	Information on COVID-19 healthcare to the society. Several job opportunities are available in relation to COVID-19.	[78]
Negative effects of COVID-19 on social	The number of days lost as a result of damages caused by COVID-19. The number of employees affected by COVID-19.	[79]

TC_{md}^{tm}: The unit shipping cost of the returned product and infectious/noninfectious waste that is unsuitable for remanufacturing, refurbishing, repairing, and recycling, from collection center m to disposal center d with shipping option tm.

TC_{fk}^{tf}: The unit shipping cost of returned product from remanufacturing/refurbishing center f to secondary market k with shipping option tf.

TC_{pk}^{tp}: Unit shipping cost of returned product from recovery and repair center p to secondary market k with shipping option tp.

TC_{rk}^{tr}: Unit shipping cost of returned product from recycling center r to secondary market k with shipping option tr.

H_m: The unit cost of COVID-19 prevention and control for collecting, inspecting, and sorting a unit of the returned product and infectious/noninfectious waste in the collection center m.

H_f: The unit cost of COVID-19 prevention and control for remanufacturing and refurbishing a unit of the returned product in the remanufacturing/refurbishing center f.

H_p: The unit cost of COVID-19 prevention and control for recovering and repairing a unit of the returned product in recovery and repairing center p.

H_r: The unit cost of COVID-19 prevention and control for recycling a unit of the returned product and infectious/noninfectious waste in the recycling center r.

H_d: The unit cost of COVID-19 prevention and control for landfilling and incinerating a unit of the returned product and infectious/noninfectious waste in the disposal center d.

HTC_{cm}^{tc}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste from customer c to collection center m with shipping option tc.

HTC_{mf}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product is available for remanufacturing and refurbishing from collection center m to remanufacturing and refurbishing center f with shipping option tm.

HTC_{mp}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product is available for recovering/repairing from collection center m to recovery and repair center p with shipping option tm.

HTC_{mr}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste is available for recycling from collection center m to recycling center r with shipping option tm.

HTC_{md}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste that is unsuitable for remanufacturing, refurbishing, repairing, and recycling from collection center m to disposal center d with shipping option tm.

HTC_{fk}^{tf}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from remanufacturing/refurbishing center f to secondary market k with shipping option tf.

HTC_{pk}^{tp}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from recovery and repair center p to secondary market k with shipping option tp.

HTC_{rk}^{tr}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from recycling center r to secondary market k with shipping option tr.

Environmental parameters:

E_m: Environmental impacts for collecting one returned product and infectious/noninfectious waste in collection center m during the COVID-19.

E_f: Environmental impacts for remanufacturing and refurbishing one returned product in remanufacturing and refurbishing center f during the COVID-19.

E_p: Environmental impacts for recovering and repairing one returned product in the recovery/repair center p during the COVID-19.

E_r: Environmental impacts for recycling the one returned product and infectious/noninfectious waste in recycling center r during the COVID-19.

E_d: Environmental impacts for landfilling and incinerating one returned product and infectious/noninfectious waste in disposal center d during the COVID-19.

$\mathrm{ETC}_{\mathrm{cm}}^{\mathrm{tc}}$: Environmental impacts by shipping option tc to send a unit of rented product and infectious/noninfectious waste from customer c to collection center m during the COVID-19.

$\mathrm{ETC}_{\mathrm{mf}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product from collection center m to remanufacturing/refurbishing f for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{mp}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product from collection center m to recovery/repairing center p for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{mr}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product and infectious/noninfectious waste from collection center m to recycling center r for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{md}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of returned product and infectious/noninfectious waste from collection center m to disposal center d for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{fk}}^{\mathrm{tf}}$: Environmental impacts by shipping option tf to send a unit of rented product from remanufacturing/refurbishing f to secondary market k for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{pk}}^{\mathrm{tp}}$: Environmental impacts by shipping option tp to send a unit of rented product from recovering/repairing center p to secondary market k for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{rk}}^{\mathrm{tr}}$: Environmental impacts by shipping option tr to send a unit of rented product from recycling center r to secondary market k for a unit distance during the COVID-19.

Social parameters:

LD_m: The average number of lost days caused by normal damages if a collection center m is open.

LD_f: The average number of lost days caused by normal damages if remanufacturing/refurbishing center f is opened.

LD_p: The average number of lost days caused by normal damages if a recovery/repairing center p is opened.

LD_r: The average number of lost days caused by normal damages if the recycling center r is opened.

LD_d: The average number of lost days caused by normal damages if disposal center d is opened.

LDC_m: The average number of lost days caused by COVID-19 damages if a collection center m is opened.

LDC_f: The average number of lost days caused by COVID-19 damages if remanufacturing and refurbishing center f is opened.

LDC_p: The average number of lost days caused by COVID-19 damages if a recovery/repairing center p is opened.

LDC_r: The average number of lost days caused by COVID-19 damages during the pandemic if the recycling center r is opened.

LDC_d: The average number of lost days caused by COVID-19 damages if disposal center d is opened.

JO_m: The number of created job opportunities if collection center m is opened.

JO_f: The number of created job opportunities if remanufacturing/refurbishing center f is opened.

JO_p: The number of created job opportunities if a recovery/repairing center p is opened.

JO_r: The number of created job opportunities if a recycling center r is opened.

JO_d: The number of created job opportunities if disposal center d is opened.

JOC_m: The number of created new job opportunities for the prevention and control of COVID-19 during collecting in the collection center m.

JOC_f: The number of created new job opportunities for the prevention and control of COVID-19 during remanufacturing and refurbishing in remanufacturing/refurbishing center f.

JOC_p: The number of created new job opportunities for the prevention and control of COVID-19 during recovering and repairing in recovery/repair center p.

JOC_{rm}: The number of created new job opportunities for the prevention and control of COVID-19 during recycling in recycling center r.

JOC_d: The number of created new job opportunities for the prevention and control of COVID-19 during landfilling and incinerating in disposal center d.

Variables:
Binary:

x_m: If collection center m is established, equal 1; otherwise 0.

x_f: If remanufacturing/refurbishing center f is established, equal 1; otherwise 0.

x_p: If recovery/repair center p is established, equal 1; otherwise 0.

x_r: If recycling center r is established, equal 1; otherwise 0.

x_d: If disposal center d is established, equal 1; otherwise 0.

Amount of returned product and waste:

Y_{cm}^{tc}: Quantity of units of returned product sent from customer c to collection center m with transportation tc.

Y_{mf}^{tm}: Quantity of units of returned product sent from collection center m to remanufacturing/refurbishing center f with transportation tm.

Y_{mp}^{tm}: Quantity of units of returned product sent from collection center m to recovery/repair center p with transportation tm.

Y_{mr}^{tm}: Quantity of units of returned product and waste sent from collection center m to recycling center r with transportation tm.

Y_{md}^{tm}: Quantity of units of returned product and waste sent from collection center m to disposal center d with transportation tm.

Y_{fk}^{tf}: Quantity of units of returned product sent from remanufacturing/refurbishing center f to secondary market k with transportation tf.

Y_{pk}^{tp}: Quantity of units of returned product sent from recovery/repair center p to secondary market k with transportation tp.

Y_{rk}^{tr}: Quantity of units of returned product sent from recycling center r to secondary market k with transportation tr.

3.2. Mathematical Model. The tri-objective design of the recovery network during the pandemic and lockdown periods is formulated as follows:

$$\begin{aligned}\text{Min } OF_1 &= \text{Total fixed cost (TFC)} + \text{Total variable cost (TVC)}\\ &\quad + \text{Total hygienic cost (THC)} + \text{Total transportation cost (TTC)},\\ TFC &= \sum_m F_m x_m + \sum_f F_f x_f + \sum_p F_p x_p + \sum_r F_r x_r + \sum_d F_d x_d,\end{aligned} \tag{1}$$

$$TVC = \sum_m C_m \sum_c \sum_{tc} Y_{cm}^{tc} + \sum_f C_f \sum_m \sum_{tm} Y_{mf}^{tm} + \sum_p C_p \sum_m \sum_{tm} Y_{mp}^{tm} + \sum_r C_r \sum_m \sum_{tm} Y_{mr}^{tm} + \sum_d C_d \sum_m \sum_{tm} Y_{md}^{tm}, \tag{2}$$

$$THC = \sum_{c}\sum_{m}\sum_{tc} TC_{cm}^{tc}Y_{cm}^{tc} + \sum_{m}\sum_{f}\sum_{tm} TC_{mf}^{tm}Y_{mf}^{tm} + \sum_{m}\sum_{p}\sum_{tm} TC_{mp}^{tm}Y_{mp}^{tm} + \sum_{m}\sum_{r}\sum_{tm} TC_{mr}^{tm}Y_{mr}^{tm}$$
$$+ \sum_{m}\sum_{d}\sum_{tm} TC_{md}^{tm}Y_{md}^{tm} + \sum_{f}\sum_{k}\sum_{tf} TC_{fk}^{tf}Y_{fk}^{tf} + \sum_{p}\sum_{k}\sum_{tp} TC_{pk}^{tp}Y_{pk}^{tp} + \sum_{r}\sum_{k}\sum_{tr} TC_{rk}^{tr}Y_{rk}^{tr},$$
$$TTC = \sum_{m} H_m \sum_{c}\sum_{tc} Y_{cm}^{tc} + \sum_{f} H_f \sum_{m}\sum_{tm} Y_{mf}^{tm} + \sum_{p} H_p \sum_{m}\sum_{tm} Y_{mp}^{tm} + \sum_{r} H_r \sum_{m}\sum_{tm} Y_{mr}^{tm} + \sum_{d} H_d \sum_{m}\sum_{tm} Y_{md}^{tm} \quad (3)$$
$$+ \sum_{c}\sum_{m}\sum_{tc} HTC_{cm}^{tc}Y_{cm}^{tc} + \sum_{m}\sum_{f}\sum_{tm} HTC_{mf}^{tm}Y_{mf}^{tm} + \sum_{m}\sum_{p}\sum_{tm} HTC_{mp}^{tm}Y_{mp}^{tm} + \sum_{m}\sum_{r}\sum_{tm} HTC_{mr}^{tm}Y_{mr}^{tm}$$
$$+ \sum_{m}\sum_{d}\sum_{tm} HTC_{md}^{tm}Y_{md}^{tm} + \sum_{f}\sum_{k}\sum_{tf} HTC_{fk}^{tf}Y_{fk}^{tf} + \sum_{p}\sum_{k}\sum_{tp} HTC_{pk}^{tp}Y_{pk}^{tp} + \sum_{r}\sum_{k}\sum_{tr} HTC_{rk}^{tr}Y_{rk}^{tr},$$

$$\text{Min } OF_2 = \text{The total environmental impacts due to activities (EP)} + \text{The total environmental impacts due to transportation (EH)},$$

$$EP = \sum_{m} E_m \sum_{c}\sum_{tc} Y_{cm}^{tc} + \sum_{f} E_f \sum_{m}\sum_{tm} Y_{mf}^{tm} + \sum_{p} E_p \sum_{m}\sum_{tm} Y_{mp}^{tm} + \sum_{r} E_r \sum_{m}\sum_{tm} Y_{mr}^{tm} + \sum_{d} E_d \sum_{m}\sum_{tm} Y_{md}^{tm} \quad (4)$$
$$+ \sum_{f} E_f \sum_{k}\sum_{tf} Y_{fk}^{tf} + \sum_{p} E_p \sum_{k}\sum_{tp} Y_{pk}^{tp} + \sum_{r} E_r \sum_{k}\sum_{tr} Y_{rk}^{tr},$$

$$EH = \sum_{c}\sum_{m}\sum_{tc} ETC_{cm}^{tc}Y_{cm}^{tc}\delta_{cm} + \sum_{m}\sum_{f}\sum_{tm} ETC_{mf}^{tm}Y_{mf}^{tm}\delta_{mf} + \sum_{m}\sum_{p}\sum_{tm} ETC_{mp}^{tm}Y_{mp}^{tm}\delta_{mp} + \sum_{m}\sum_{r}\sum_{tm} ETC_{mr}^{tm}Y_{mr}^{tm}\delta_{mr}$$
$$+ \sum_{m}\sum_{d}\sum_{tm} ETC_{md}^{tm}Y_{md}^{tm}\delta_{md} + \sum_{f}\sum_{k}\sum_{tf} ETC_{fk}^{tf}Y_{fk}^{tf}\delta_{fk} + \sum_{p}\sum_{k}\sum_{tp} ETC_{pk}^{tp}Y_{pk}^{tp}\delta_{pk} + \sum_{r}\sum_{k}\sum_{tr} ETC_{rk}^{tr}Y_{rk}^{tr}\delta_{rk}, \quad (5)$$

$$\text{Min } OF_3 = \left[\left(LD_m x_m + LD_f x_f + LD_p x_p + LD_r x_r + LD_d x_d + LDC_m x_m + LDC_f x_f + LDC_P x_p LDC_r.x_r + LDC_d.x_d\right)\right]$$
$$\left[\left(-JOm x_m + JOf x_f + JOp x_p + JOr x_r + JOd x_d + JOC_m.x_m + JOC_f.x_f + JOC_r.x_r + JOC_p.x_p + JOC_d.x_d\right)\right]. \quad (6)$$

Subjected to:

$$\sum_{f}\sum_{tm} Y_{mf}^{tm} \le CAPm \,\forall m. \quad (7)$$

$$\sum_{p}\sum_{tm} Y_{mp}^{tm} \le CAPm \,\forall m, \quad (8)$$

$$\sum_{p}\sum_{tr} Y_{mr}^{tm} \le CAPm \,\forall m, \quad (9)$$

$$\sum_{d}\sum_{tm} Y_{m\,d}^{tm} \le CAPm \,\forall m, \quad (10)$$

$$\sum_{k}\sum_{tf} Y_{fk}^{tf} \le CAPf \,\forall f, \quad (11)$$

$$\sum_{k}\sum_{tp} Y_{pk}^{tp} \le CAPp \,\forall p, \quad (12)$$

$$\sum_{k}\sum_{tr} Y_{rk}^{tr} \le CAP\mathrm{r} \,\forall r, \quad (13)$$

$$\sum_{k}\sum_{tf} Y_{fk}^{tf} \le \sum_{m}\sum_{tm} Y_{mf}^{tm} \,\forall f, \quad (14)$$

$$\sum_{k}\sum_{tp} Y_{pk}^{tp} \leq \sum_{m}\sum_{tm} Y_{mp}^{tm}\ \forall p, \tag{15}$$

$$\sum_{k}\sum_{tr} Y_{rk}^{tr} \leq \sum_{m}\sum_{tm} Y_{mr}^{tm} \forall r, \tag{16}$$

$$\sum_{d}\sum_{tm} Y_{m\,d}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{17}$$

$$\sum_{r}\sum_{tm} Y_{mr}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{18}$$

$$\sum_{p}\sum_{tm} Y_{mp}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{19}$$

$$\sum_{f}\sum_{tm} Y_{mf}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc} \forall m, \tag{20}$$

$$\sum_{m}\sum_{tc} Y_{cm}^{tc} \leq \Omega_c\ \forall c, \tag{21}$$

$$Y_{cm}^{tc}.Y_{mf}^{tm}.Y_{mp}^{tm}.Y_{mr}^{tm}.Y_{m\,d}^{tm}.Y_{pk}^{tp}.Y_{rk}^{tr}.Y_{fk}^{tf} \geq 0\ \forall m.\forall f.\forall p.\forall r.\forall d.\forall c, \tag{22}$$

$$X_m.X_f.X_r.X_p.X_d\{0.1\}\ \forall m.\forall f.\forall r.\forall p.\forall d. \tag{23}$$

The OFs: The mathematical formulations of the OFs are described in equations (1)–(6). The total cost is the summation of the fixed costs, the variable cost, the total shipping cost, and the total hygienic cost. The total impacts of COVID-19 on the environment are calculated by consideration of the negative and positive due to collecting, remanufacturing, refurbishing, recovering, repairing, recycling, disposing, and shipping during the COVID-19 and lockdowns. The total bad social impact is calculated by subtracting the number of lost days and created job opportunities throughout RN during the COVID-19.

The constraints of the model are shown in equations (7)–(23).

Constraint (7) states the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any remanufacturing and refurbishing centers via any shipping options must be less than or equal to the collection center's capacity. Constraint (8) shows the total number of returned product units shipped from a collection center to any recovery and repair center via any shipping options must be less than or equal to the collection center's capacity. Constraint (9) presents the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any recycling center via any shipping options must be less than or equal to the collection center's capacity. Constraint (10) describes the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any disposal center via any shipping options must be less than or equal to the collection center's capacity. Constraint (11) explains the total number of returned product units shipped from a remanufacturing and refurbishing center to any secondary markets via any shipping options must be less than or equal to the remanufacturing and refurbishing center's capacity. Constraint (12) illustrates the total number of returned product units shipped from a recovery and repair center to any secondary markets via any shipping options must be less than or equal to the recovery and repair center's capacity. Constraint (13) shows the total number of the returned product and infectious/noninfectious waste units shipped from the recycling center to any secondary markets via any shipping options must be less than or equal to the recycling center capacity. Constraint (14) describes the total number of returned product units shipped from a remanufacturing and refurbishing center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any remanufacturing and refurbishing centers. Constraint (15) states the total number of returned product units shipped from the recycling center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any recycling center. Constraint (16) shows the total number of returned product units shipped from a recovery and repair center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any recovery and repair center. Constraint (17) describes the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any disposal center. Constraint (18) states the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any recycling center. Constraint (19) shows the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any recovery and repair center. Constraint (20) describes the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any remanufacturing and refurbishing center. Constraint (21) explains the total quantity of units of the returned product collected from a customer to any collection centers through any shipping options should be lower than the respective customer's returned product. Constraint (22) narrates the total number of the returned product and infectious/noninfectious waste flowed from a customer c to a collection center m via a shipping method, a collection center m to a remanufacturing/refurbishing center f via a shipping method, a collection center m to a recovery and repair center p via a shipping method, a collection center m to a recycling center via a shipping mode, and a collection center m to a disposal center via a shipping mode. The number of the returned products for remanufacturing, refurbishing, recovering and repairing, or recycling from F, P, R to secondary market(s) are equal or greater than zero. Constraint (23) describes binary number for the potential of facilities (M, F, P, R, and D).

3.3. Solution Approach. In multi-objective optimization problems (MOOPs), two or more objective functions are minimized or maximized. The Pareto-optimal set (POS) consists of the nondominant set of entirely possible decision spaces. The Pareto-optimal front (POF) is the bounder specified by the POS for a collection of points.

3.3.1. Weighted Sum Method. Scalarization is the traditional method of solving MOOP, which involves formulating a single-objective optimization problem (SOOP) associated with the MOOP [80].

$$\begin{aligned}&\min\left(f_1(x),\ldots,f_p(x)\right).\\&\text{subjec to: } x\in X.\end{aligned}\tag{24}$$

The weighted sum method (WSM) uses the vector of weights $\lambda \in R^p \geq$ as a parameter [80].

$$\begin{aligned}&\min\sum_{k=1}^{p}\lambda_k f_k(x),\\&\text{subjec to: } x\in X.\end{aligned}\tag{25}$$

To manage the WSM, each aspect must be weighed and the weighted sum must be minimized. Solving MOP with the SO approach is the excellence of this method [81].

Three OFs can be solved with WSM:

$$\text{Minimize}\, w_1 f_1 + w_2 f_2 + w_3 f_3. \tag{26}$$

Subject to equations (7)–(23), where $w_1 \geq 0$, $w_2 \geq 0$, and $w_3 \geq 0$ are weights such that $w_1 + w_2 + w_3 = 1$; and f_1, f_2, and f_3 the OFs. For a better understanding of the Pareto concept, we present Figure 4 [80–82].

3.3.2. Pareto Frontier. The solution method is described in this section. The nondominant solutions to MOOP are well known. We call them Pareto-optimal solutions. This paper aims to provide an evenly distributed Pareto solution via a frontier from Pareto. This makes it easier for DMs to choose the right configuration. By demonstrating that the design space is well represented in the Pareto set, a Pareto distribution solution makes it easier for decision-makers to make a decision. The MO model has three OFs, and the objective value of these three functions is illustrated by f_1, f_2, and f_3, respectively. Once the model has been solved with each OF separately, we can obtain the objective values f_1^*, f_2^*, and f_3^* corresponding to objectives one, two, and three, respectively. In the end, the Pareto set was generated. For the Pareto-optimal set and the solution of the model, we will use the MOMIP solver Lingo. An example numerical example and case study are then used to test the model.

4. Numerical Examples and Case Study

A numerical example and case study are created to demonstrate and analyze the model performance. The reverse network in the proposed numerical example comprises seven facilities: customers, collection centers, remanufacturing/refurbishing centers, recovery/repair centers, recycling centers, and disposal centers. Potential locations of RN facilities (M, F, P, R, and D) and existing C and K are given, shipping options from customers, collection centers, remanufacturing/refurbishing centers, recovery/repair centers, and recycling centers (TC, TM, TF, TP, and TR). Table 3 provides information about facilities and transportation. Suppose we focus on economic, environmental, and social impact during the COVID-19 pandemic, in that case, the total environmental effect is calculated by adding the total impacts due to collecting returned production and infectious/noninfectious waste, remanufacturing, refurbishing, recovering, repairing, recycling, landfilling, incinerating, and the total impacts due to shipping. It has been assumed all activities in this model are observance of hygiene protocol during the COVID-19 pandemic and lockdowns. The problem in the small dimension is depicted in Figure 5.

The Pareto frontier of the numerical example and the case study is illustrated in Figures 6–9.

4.1. Sensitivity Analysis of Optimization Value (Base Scenario). A sensitivity analysis is performed to investigate the effects of model parameters. The optimization of the solutions was analyzed about changes in the conditions of the problem. In two different scenarios, we compare the economic, environmental, and social objective functions.

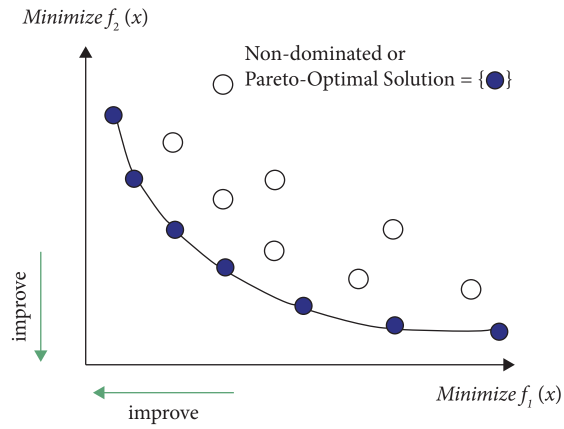

Figure 4: Graphic depiction of the Pareto solutions.

Table 3: Number of facilities and transportation mode.

Indices	Values
C	{1, 2, 3, . . ., 5}
M	{1, 2, 3, . . ., 7}
F	{1, 2, 3, . . ., 5}
P	{1, 2, 3, . . ., 6}
R	{1, 2, 3, 4}
D	{1, 2, 3, 4}
K	{1, 2, 3}
TC	{1, 2, 3, 4}
TM	{1, 2, . . ., 6}
TF	{1, 2}
TP	{1, 2, 3}
TR	{1}

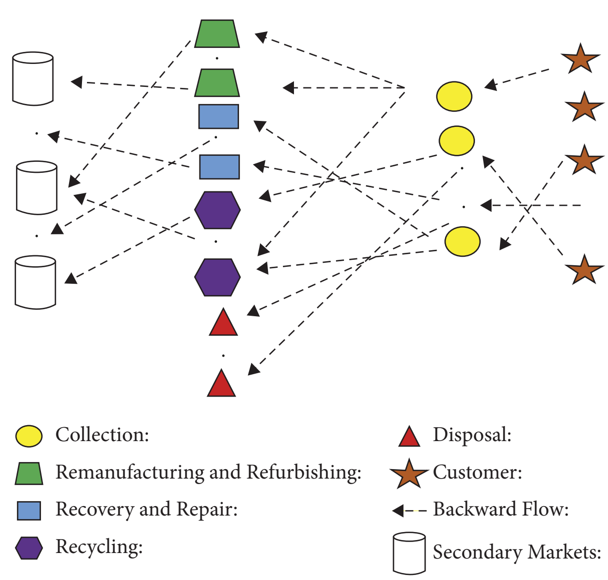

Figure 5: Locations of RN facilities in small dimension.

Under different scenarios, such as fallow, the economic, environmental, and social objectives are valued differently. The optimization value of the economics, environmental, and social aspects with normal and COVID-19 conditions is analyzed in Tables 4–6.

The findings of the proposed network demonstrated that the RN has become environmentally sustainable. Under the COVID-19 scenario, the environment objective function optimization value is better than under the normal scenario (Figure10). With the normal scenario, the economic objective function optimizes better than with COVID-19 (Figure 11). Under the normal scenario, the social objective function optimizes better than in the COVID-19 situation scenario (Figure 12).

4.2. Sensitivity Analysis of Dimensions of the Problem. Several numerical examples in different dimensions (small, medium, large) are used to examine the performance of SRN. 15 numerical examples are provided in this regard. Information about the dimensions of the problems is shown in Table 7, and the results of solving are presented in Table 8. By considering this matter, we have done a sensitivity analysis. The number of shipping options is fixed, and it is one during the recovery network ($|tc| = |tm| = |tf| = |tp| = |tr| = 1$).

As the dimensions of the problem increase, the OF's value increases. By increasing the dimensions of a problem, the optimal value of each OF increases. According to Figures 13–15, these increases do not follow a linear pattern, and the rate of rising varies from case to case. The proposed model can find the optimal solution in varying conditions and situations, as demonstrated by several examples of small, medium, and large dimensions

5. Managerial Implications and Practical Insights

In this study, the RND was designed for the COVID-19 outbreak. As a result of this research, useful policies for disaster management will be produced, especially if COVID-19 conditions are observed, and the relevant managers will be able to do the following: (i) management of the RN should have considered the hygienic costs associated with their RN. (ii) Employees should be able to be replaced when disasters arise. (iii) Managers have a responsibility to inform employees about COVID-19's negative consequences. (iv)

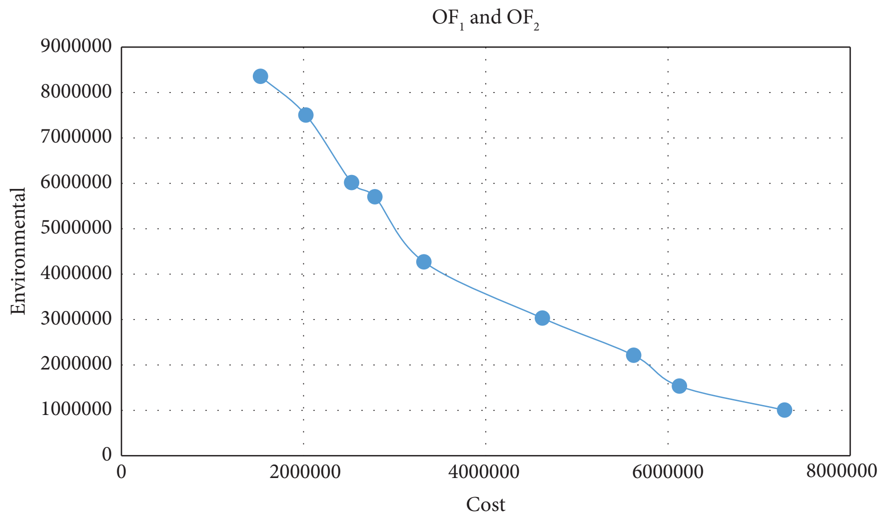

Figure 6: Pareto frontier of the numerical example.

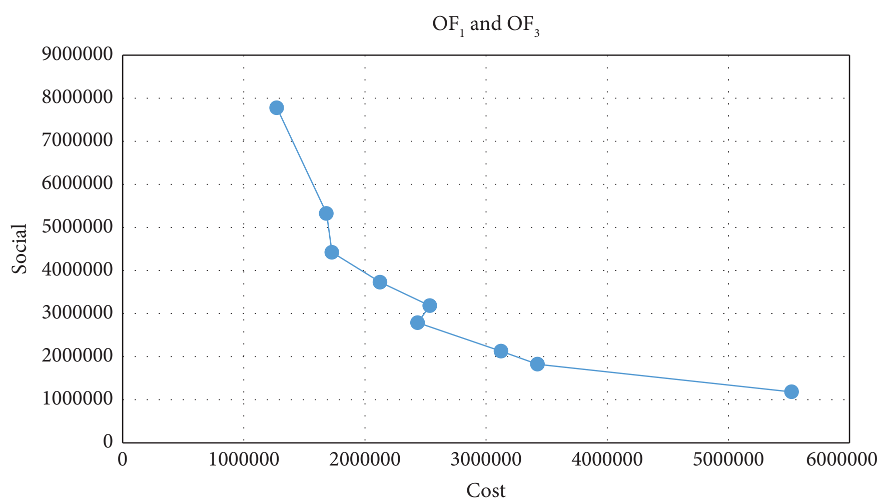

Figure 7: Pareto frontier of the numerical example.

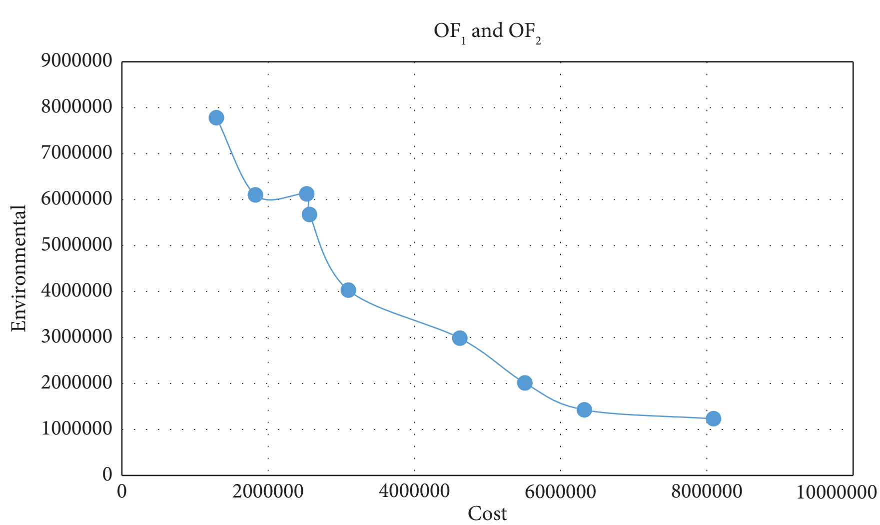

Figure 8: Pareto frontier of the case study.

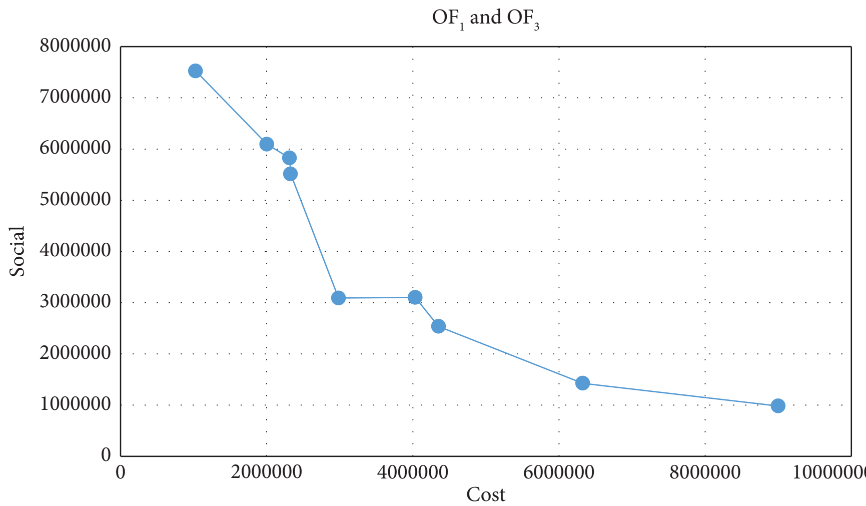

Figure 9: Pareto frontier of the case study.

Table 4: The optimization value of the economics OF with different scenarios.

Number	(Normal condition) considering model with hygienic cost	Number	(COVID-19 condition) considering model without hygienic cost
Situation 1	(i) Normal fixed costs (ii) Normal variable costs (iii) Shipping costs (iv) Z^* normal = 5527638	Situation 2	(i) Fixed costs (ii) Variable costs (iii) Shipping costs (iv) Hygienic costs (v) Z^* COVID-19 = 6010112

Table 5: The optimization value of the environmental OF with different scenarios.

Number	(Normal condition) total environmental impact without concerning COVID-19	Number	(COVID-19 condition) total environmental impact concerning COVID-19
Situation 1	(i) Normal plastic waste. (ii) Normal soil pollution. (iii) Normal gas emissions of industrial activities. (iv) Normal gas emissions of shipping activities. (v) Normal water consumption and pollution due to noninfectious waste (vi) Z^* normal = 2786549	Situation 2	(i) Plastic and PPE waste during the COVID-19 pandemic. (ii) Soil pollution during the COVID-19 pandemic. (iii) Gas emissions of industrial activities during the COVID-19 pandemic and lockdown periods. (iv) Gas emissions of shipping activities during the COVID-19 pandemic and lockdown periods. (v) Water consumption and pollution during the COVID-19 pandemic. (vi) Infectious waste. (vii) Z^* COVID-19 = 1987652

Table 6: The optimization value of the social OF with different scenarios.

Number	Normal condition model total social impact without concerning COVID-19	Number	COVID-19 condition model total social impact concerning COVID-19
Scenario 1	(i) Customers' service satisfaction. (ii) The average number of lost days caused by normal damages (iii) The number of created normal job opportunities. (iv) Z^* normal = 8109287	Scenario 2	(i) Customers' service satisfaction in a disaster situation. (ii) The average number of lost days caused by COVID-19 damages (iii) The number of created new job opportunities to prevent and control COVID-19. (iv) Z^* COVID-19 = 9087321

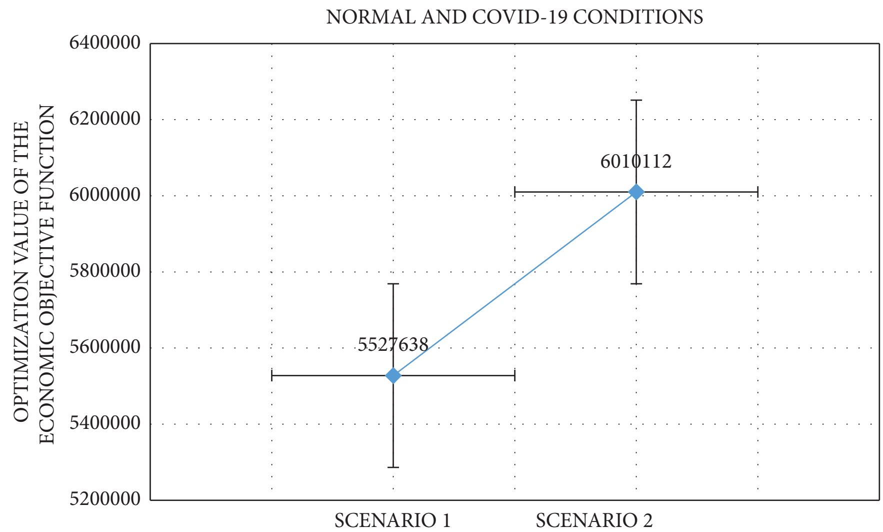

Figure 10: Sensitivity analysis of economic aspect (normal COVID) models.

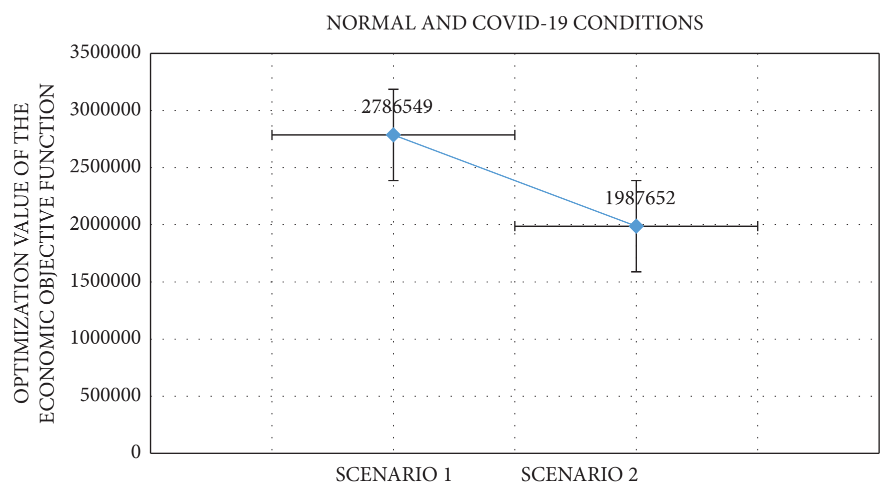

Figure 11: Sensitivity analysis of environmental aspect (normal COVID) models.

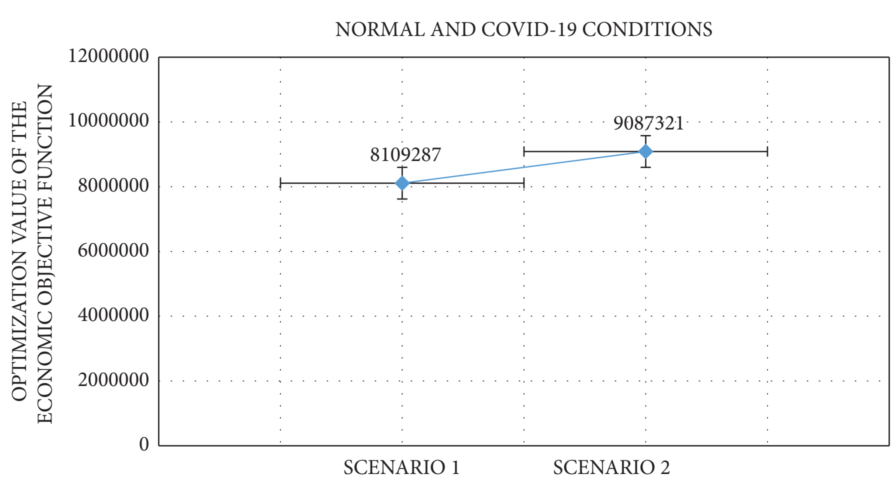

Figure 12: Sensitivity analysis of social aspect (normal COVID) models.

Table 7: Dimensions of design numerical examples.

Dimensions	Name	$\|C\|$	$\|M\|$	$\|F\|$	$\|P\|$	$\|R\|$	$\|D\|$	$\|K\|$
Small	P1	4	2	1	2	2	1	3
	P2	5	3	2	2	3	3	4
	P3	6	3	2	3	4	3	4
	P4	8	4	3	3	4	4	5
	P5	9	5	4	5	5	6	7
Medium	P6	10	8	5	6	6	7	8
	P7	13	7	5	7	6	8	8
	P8	15	7	5	7	6	10	11
	P9	17	8	6	8	8	11	13
	P10	20	8	6	10	9	12	15
Large	P11	22	9	7	12	10	14	18
	P12	23	9	9	13	11	16	20
	P13	25	10	11	13	12	16	21
	P14	30	11	15	14	13	18	26
	P15	40	11	15	14	16	20	30

Table 8: Results of solving.

Name	Optimal economic value	Optimal environmental value	Optimal social value	Solution time (seconds)
P1	320011.5	520412.2	2300.007	0.13
P2	330011.5	728314.0	2500.119	0.14
P3	340011.5	827510.7	2784.157	0.16
P4	370010.8	958620.1	3009.100	0.16
P5	390012.9	1038509.9	3004.280	0.17
P6	403486.5	1028509.0	3164.000	0.19
P7	501435.6	10290807.8	3260.000	0.22
P8	511123.5	1128509.1	3252.000	0.22
P9	598003.9	1210045.9	4820.000	0.25
P10	623191.9	1319945.4	5312.000	0.27
P11	822251.9	1411145.0	5648.000	0.27
P12	929260.5	1612345.0	5500.990	0.27
P13	1087650.8	1912345.0	5809.990	0.29
P14	1153370.5	2028615.0	6207.120	0.31
P15	1291010.3	2023231.0	6607.000	0.33

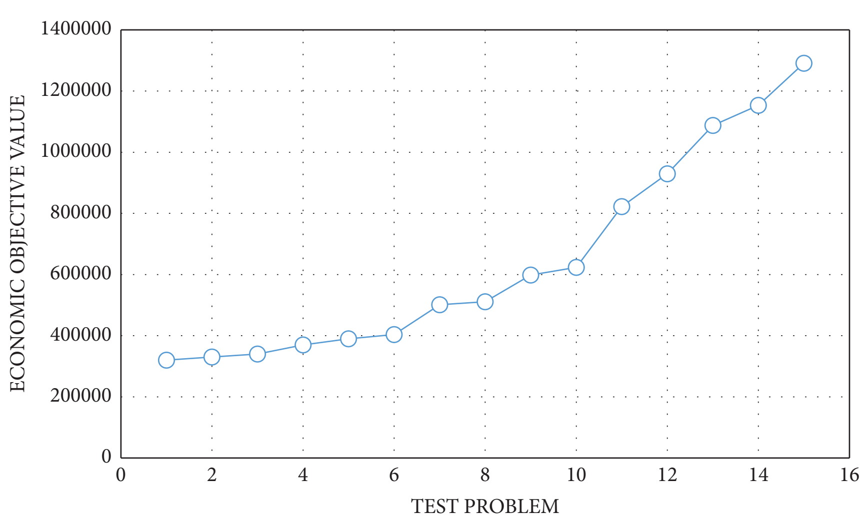

Figure 13: The value of the economics OF with different scenarios.

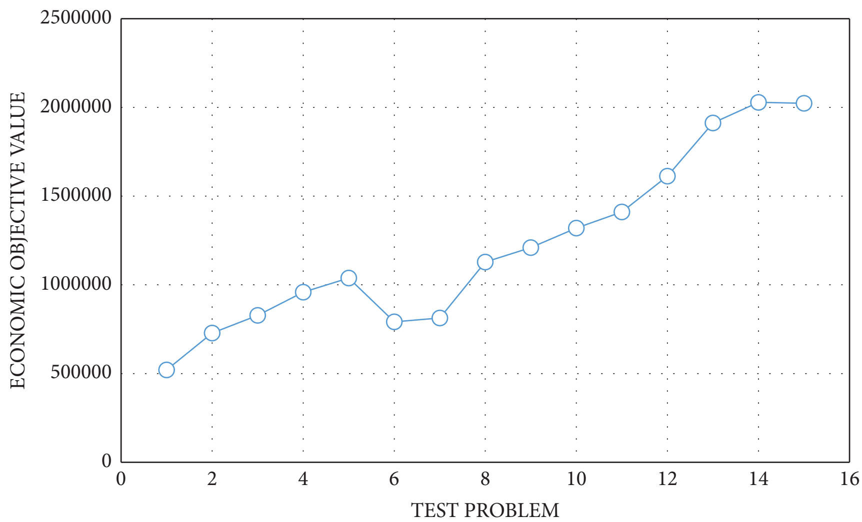

Figure 14: The value of the environmental OF with different scenarios.

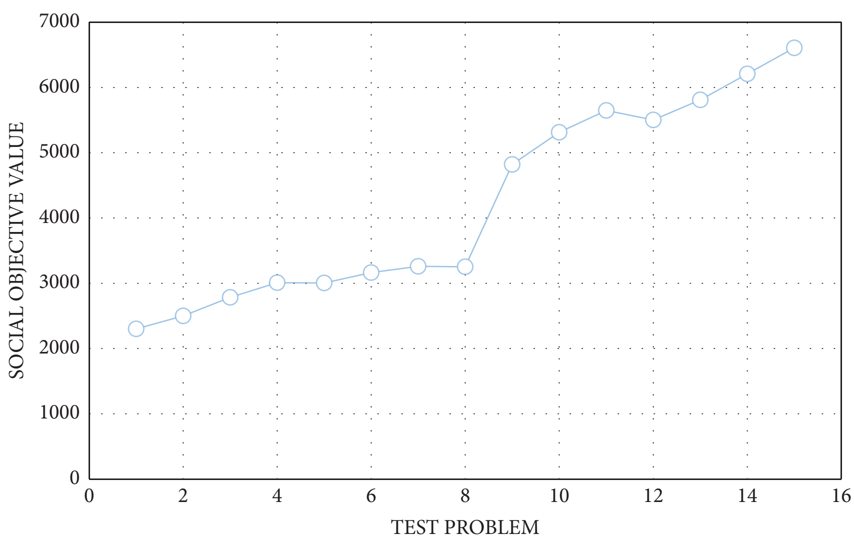

Figure 15: The value of the social OF with different scenarios.

During the collection of hazardous waste, managers should consider the health of workers. Finally, this study provides insight into how the RN can manage during the COVID-19 pandemic.

6. Conclusion, Limitations, and Future Works

During the COVID-19 disaster, this paper examined urgent global issues concerning returned products and waste management. RNs are impacted by COVID-19, and it is an exceptionally rare and extraordinary event. This study proposed the model for sustainable end-of-life management (SEOLM) during the COVID-19 pandemic. First, a review of previous related studies was conducted. Subsequently, a sustainable recovery network (SRN) was developed, based on the latest research items. The model consists of customers, collection centers, remanufacturing and refurbishing centers, recovery and repair centers, recycling centers (normal/COVID-19), landfills and incineration (Disposal) centers (normal/COVID-19), and secondary markets (Reuse markets). A MOMIP problem model has been proposed for SRN during COVID-19 and lockdown periods. The suggested mathematical model is formulated by considering the multidimensional aspects of sustainability, minimizing costs, minimizing bad environmental effects, and minimizing bad social effects. For the scalarization approach, we use the WSM. This process was optimized by using Lingo software. An example case study and numerical example were used to illustrate the validation of the presented model, along with a diagram of the Pareto front. A model such as this is sensitive to cost structure, so the model includes both normal costs and COVID-19 costs. Among the main findings of our paper were as follows: proposed a new model for SRN to demonstrate better the trade-offs between various aspects of sustainability in pandemics and lockdowns, (ii) designing the hygiene and safe workplace for the employees and employers in RN (especially hazard waste), (ii) developing indicators of the social, environmental, and economic dimensions, and (iv) RN has experienced both negative and positive effects of COVID-19 and lockdowns.

Our study has several limitations that need to be addressed in future research:

(i) Only one real company provided us with data.

(ii) Due to the lack of accurate information, some of the data was estimated.

(iii) The model is a single product and single-period network designed.

(iv) Lack of scientific resources and available statistics and information: In this regard, some problems have made research services such as access to books, journals, statistics, and databases in the country not easily possible.

(v) Limited budget required to do and advance the work: Each research work in its various stages requires spending financial costs, which indeed student research, due to the particular circumstances of the researcher, is no exception.

(vi) The research was conducted in Iran, and we do not know how much it is coordinated with other countries. Still, we tried to solve this problem by using different research sources and their statistical sources, standardizing the research, and bringing this research closer to the real world around the globe.

(vii) The research has been done cross-sectional; because of this, it makes it challenging to conclude causality.

Future work should include the following recommendations:

(i) In RN, consider the concept of responsiveness during COVID-19.

(ii) Improved the model by considering multi-product.

(iii) Considering model with multi-period.

(iv) Solving the model with other methods and compeering it with this method, for example, LP metric method and genetic algorithms optimization.

(v) Considering the uncertainty returned product for the model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

The mathematic model is solved with Lingo software. The Lingo code is available and can be present if necessary.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors contributed to development of this study. All authors read and approved the final manuscript.

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Research Article

Optimal Decision and Coordination of Organic Food Supply Chain from the Perspective of Blockchain

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Driven by the pain points of the organic food supply chain, which has been plagued by counterfeiting and difficulties in pursuing accountability, this paper investigates a secondary organic food supply chain consisting of suppliers and retailers and establishes two supply chain models under the traditional model and in the blockchain traceability context. In order to effectively solve the problem of unrealized Pareto improvement in organic food supply chain after applying blockchain, a new hybrid contract based on benefit-sharing and cost-sharing is designed to coordinate the supply chain and realize Pareto improvement, and this solution is gradually applied to organic food enterprises. Based on the fact that blockchain can improve trust in the supply chain and eliminate counterfeiting of organic food, the relationship between the rate of genuine products and market demand and the cost of blockchain is established, and then the analysis is developed using the Stackelberg game. We compare the traditional model with the model in the blockchain context and analyze the optimal profit of each supply chain entity, comparing the change in optimal profit before and after the blockchain implementation, and clarifying the cost threshold of the blockchain technology input application. We find that: (i) The adoption of blockchain can not only improve the authenticity of products and combat counterfeit and shoddy organic food, but at the same time, the improvement of organic level in the context of blockchain will also attract some consumers to buy organic food, which will increase the main body of the supply chain and the overall profit. (ii) Blockchain-adopted supply chains are consistently more profitable for all parties and overall than traditional supply chains. The main contribution of this study is that in the organic food supply chain under the application of blockchain technology model, by introducing revenue-sharing and cost-sharing contracts, the profit between each member of the organic food supply chain is further improved than the traditional model, and also, all of them are optimized, which further improves the stability of the supply chain and brings the supply chain to a coordinated state. Finally, in this context, the obtained results show the effectiveness and realistic operational efficiency of the proposed approach for companies compared to traditional single revenue-sharing covenants. A combination of revenue-sharing and cost-sharing covenants is the best approach to solve such problems. In conclusion, it should be noted that the analysis presented in this study will help decision makers choose the most appropriate option among the possible solutions according to their criteria. This proposed framework can also be extended in various cases where profits are out of balance in the organic food supply chain, such as safety and value gain.

1. Introduction

According to Blueweave Consulting & Research Pvt. Ltd., the global organic food market is expected to grow at a compound annual growth rate (CAGR) of over 15% from 2018 to 2026, driving consumers to purchase organic food. The main reason for purchasing organic food is health, and customers with healthy eating habits are more likely to buy organic food [1]. Organic food is now one of the fastest growing segments of the food market, with significant increases in production and sales in many developing countries. The consumer demand in China's organic food market is gradually becoming larger, and the number of consumers buying organic food is increasing, involving organic food products such as dairy products and vegetables [2, 3].

The organic food supply chain has always had the pain point of counterfeiting and accountability [4]. The current traceability technology cannot prevent organic food information from being tampered with, resulting in general mistrust between the upstream and downstream of the organic food supply chain, uncoordinated supply chain management, and low efficiency [5, 6]. Since the Japanese scholar Satoshi Nakamoto proposed the blockchain in 2008, blockchain technology has entered the public's field of vision as the underlying technology of Bitcoin. Due to the unique characteristics of the blockchain, people soon began to realize the block chain. The application prospect of blockchain technology has caused a frenzy of research on blockchain in the world [4]. One of the cores of the blockchain is to increase trust. It establishes mutual trust relationship through peer-to-peer network, encryption algorithm, time stamp, and other technologies, which plays an important role in enhancing the trust cooperation relationship between supply chains and improving supply chain coordination [7]. After years of development, blockchain has begun to extend to finance, supply chain management, logistics, traceability, and other important areas, of which anti-counterfeiting traceability of agricultural products is one of the main applications in traceability. Organic food is quite popular among global consumers because its healthy and green. In the past five years, the production of organic food in China has been rising and the market scale has been expanding, but the painful problem of counterfeiting in the distribution process has not been solved. The traditional organic food supply chain distribution system is prone to information tampering and low data security, coupled with information asymmetry and difficulty in accurate traceability, resulting in unscrupulous organic food manufacturers in the supply chain making use of substandard products and adulterating them [8]. In the circulation process of organic food, confusing labels and counterfeiting of trademarks occur from time to time, and the tampering of organic food information is even more difficult to prevent [9]. In the upstream of the supply chain, it is still genuine organic food, but when it reaches downstream distributors and retailers, it is discarded by low-quality and shoddy organic food. The supply chain is filled with a large number of fake and shoddy organic foods that cannot be accurately identified the organic food supply chain. The trust between them has long existed in name only, which has seriously affected the cooperation and coordination among the members of the supply chain and hindered the development of the organic food industry [10]. Although many large organic food companies spend a lot of operating cost every year to fight counterfeiting and anti-counterfeiting and maintain their own brand products, the results are minimal, and it is still difficult to solve the problems of trust and counterfeiting in the organic food supply chain. The immutable nature of the blockchain has brought opportunities to combat counterfeit and shoddy organic food and establish a traceability system that can be traced throughout the entire process. Its encryption algorithm, peer-to-peer network, consensus mechanism, and other technologies have created conditions for the establishment of trust between supply chains [11]. With the continuous development of blockchain technology, many companies have begun to study blockchain-based traceability management systems [12]. In the past two years, more and more enterprises have used blockchain technology to trace the whole process of organic food, combat the phenomenon of counterfeiting and shoddy organic food in the supply chain, protect the real organic food, and reshape the relationship between the upstream and downstream of the organic food supply chain. Trust can improve the collaboration efficiency between supply chains and achieve supply chain coordination. With the continuous development of blockchain technology, many countries are aware of the application prospects of blockchain in traceability [13, 14]. Based on the fact that the information on the blockchain cannot be tampered with, the authenticity of the product can be guaranteed when the blockchain is used for traceability. Therefore, in recent years, some large enterprises in China have begun to seize the opportunity to enter the blockchain traceability market [5]. At present, the development of blockchain is in a period of rapid development, and the application of blockchain is no longer limited to the financial field. During this period, a large number of entrepreneurs began to create blockchain companies, and people began to explore the application of blockchain technology in other fields. The value and prospect are, respectively, applied to logistics, supply chain management, medical care, and education. Currently, there are more applications in the field of supply chain finance [15–17].

Lotfi et al. [18] considered a closed-loop supply chain by taking into account sustainability, resilience, robustness, and risk aversion for the first time. Lotfi et al. [19] proposed that the use of blockchain Technology (BCT) is growing faster in each country. Blockchain can improve transparency, trust, information sharing, security, and ensure information is not tampered with in the organic food supply chain [20]. By using blockchain technology, it helps to share information between members and reduce transaction costs between companies in the organic food supply chain [21]. The supply chain information system built using blockchain effectively connects all supply chain entities and facilitates the exchange of information in the supply chain [22]. The technical characteristics of blockchain, such as nontampering of information, open and transparent information, and time stamp, provide new ideas for solving the problem of counterfeiting and counterfeiting of organic food and reshaping the trust between organic food supply chains. The whole process of anti-counterfeiting traceability system of food can prevent counterfeit and shoddy organic food from flowing into the supply chain, enhance trust between the upstream of the organic food supply chain, and promote the supply chain to achieve a coordinated state. Although the blockchain is still in the initial stage of development, it is believed that under the promotion of national policies, in the context of the urgent needs of the organic food industry, and the unique advantages of blockchain in anti-counterfeiting and traceability, and establishing trust in the supply chain, future applications blockchain traceability of organic food will become a norm, so it is of practical significance for us to study the coordination of the organic food supply chain based on blockchain technology.

Based on this, in the context of blockchain technology, this paper studies the coordination of organic food supply chain, and introduces appropriate supply chain contracts to coordinate the profits of supply chain members. The following questions are mainly investigated:

(1) Under decentralized decision-making, which model is more profitable for retailers compared to the traditional model and the blockchain model?
(2) Under decentralized decision-making, does the supply chain in the context of blockchain reach the optimal state?
(3) In the traditional supply chain, how does the genuine rate of organic food affect the profit of the supply chain?
(4) Are supply chains that adopt blockchain more profitable than traditional supply chains? Can supply chain adoption of blockchain improve efficiency?
(5) How do cost-sharing and revenue-sharing factors affect supply chain profitability?
(6) How to encourage organic food manufacturers to actively adopt blockchain technology, trace the source of the whole process, maintain the brand image of organic food, and put it into the supply chain to achieve supply chain collaboration and improve supply chain performance?

We consider a secondary supply chain model consisting of an organic food producer and a retailer. We take the serious phenomenon of organic food counterfeiting and the distrust between the supply chain subjects as the research background, and use the characteristics of blockchain on-chain information being tamperproof and traceable as the basis. Introducing blockchain can eliminate the counterfeiting of organic food, improve the organic degree between the supply chain subjects, and make the organic food supply chain achieve coordination as the goal, and on this basis, we study the contractual coordination problem of the organic food supply chain. We construct a supply chain game model based on two scenarios: the blockchain model and the traditional model, and compare and analyze the optimal profit of each supply chain subject. Comparing the change in optimal profit before and after the implementation of blockchain, we further study the cost threshold of blockchain technology input application.

The main contribution and motivation of this study are as follows:

(1) Under the traditional model, the increase in organic food authenticity will bring higher profits to the supply chain.
(2) The adoption of blockchain can increase the rate of organic food authenticity and combat counterfeit organic food, while the increase in trust in the blockchain context will attract some consumers to buy organic food and bring additional revenue to the supply chain.
(3) As there is no counterfeiting and trust is improved in the blockchain context, the profit of the supply chain is always higher than that of the traditional supply chain, which also shows that the adoption of blockchain can improve the efficiency of the supply chain.

We organized this paper as follows. In Section 2, we study on related work and show gap research within the organic food supply chain in the context of blockchain technology. In Section 3, we determine the blockchain model of organic food and the mathematical model of the traditional model. In Section 4, we detail management insights from the industrial case. In Section 5, the findings and results of the proposed model with sensitivity analysis are explained. In Sections 6 and 7, the managerial insights and conclusion and outlook are determined. All proofs are relegated to Appendix.

2. Literature Review

Based on the topics we discuss, our work involves the following three aspects. This section briefly reviews related concepts, including blockchain, organic food supply chains, and supply chain contracts to provide some background information based on our research. Therefore, we will summarize the literature from the above three aspects.

2.1. Blockchain. The blockchain is now more and more valued by the country and all walks of life. By sorting out the blockchain traceability and the research status of our paper, there are mainly the following two aspects: on the one hand, blockchain can improve the transparency and trust of supply chain information degree, information sharing, and security to ensure that information is not tampered with. Bodkhe et al. [23] found that the application of blockchain technology helps to realize information sharing among members and reduce transaction costs among supply chain enterprises. Berdik et al. [24] used the supply chain information system constructed by the blockchain to effectively connect the main bodies of the supply chain and promote the exchange of information in the supply chain. Lu [25] proposed an agricultural product system architecture model based on the consortium blockchain based on the decentralization characteristics of blockchain technology, thereby preventing network attacks and ensuring the security and reliability of agricultural product data. Monrat et al. [26] proposed to use blockchain technology to build a consortium chain to solve the problem of trust between cross-border e-commerce and domestic e-commerce and the quality and safety of goods. Zhou et al. [27] concluded that the application of blockchain will solve the problem of information asymmetry in financial institutions and reduce risks through theoretical analysis. Morkunas et al. [28] used the newsboy model to analyze that the blockchain debt swap platform has high trust, high efficiency, easy operation, low cost, and higher financing efficiency. Singh et al. [29] showed that blockchain technology can overcome collaboration and trust issues in supply chains and minimize the negative consequences of eliminating information asymmetry in supply chain echelons. To make the agricultural supply chain more transparent, Chang et al. [30] proposed a dual-chain storage structure characterized by a chained data structure for storing blockchain transaction hashes, with the aim of ensuring that agricultural product data is not tampered with or destroyed. On the other hand, the record information of the blockchain cannot be calculated and traced, which is suitable for solving the problem of counterfeiting and shoddy, and can carry out product information traceability and anti-counterfeiting, which has a good effect on solving the long-standing pain point of counterfeiting.

In recent years, many experts and scholars have used blockchain as a tool to study and solve the problems of product traceability and anti-counterfeiting. Feng et al. [31] proposed that the integration of blockchain technology and IoT technology can solve the problems of easy calculation, modification, and counterfeiting of cross-border e-commerce product information. Andoni et al. [32] believe that the immutable characteristics of blockchain and timestamp technology can be used to solve the problems of data tracking and information anti-counterfeiting. Dutta et al. [33] proposed that because blockchain technology information cannot be tampered with, and information is updated and stored in real-time, it has great advantages for supply chain cost control, and information is difficult to tamper with, which is conducive to supply chain anti-counterfeiting traceability. Deepa et al. [34] built a blockchain-based agricultural product traceability system, which helped solve the problem of insecure agricultural product data and information, protected consumers' rights and interests, and improved consumers' confidence in products. Other scholars have also conducted in-depth discussions on blockchain traceability, and began to study the construction of blockchain-based traceability systems and frameworks and applied them to different subjects. Upadhyay [35] proposed a blockchain-based framework that can successfully handle the critical recovery problem, preventing cloning attacks, counterfeit labels, and counterfeit products. Gai et al. [36] constructed a blockchain-based logistics monitoring system to provide a solution for package tracking in supply chains. Xu et al. [37] described the integration of blockchain into supply chain architecture to solve the problems of corruption, fraud, and tampering faced by supply chains in centralized supply chain management systems. Zhang and Lee [38] discussed the tracking and traceability of soybean supply chain using the potential of blockchain and smart contracts.

After summarizing the domestic and foreign research status of the above blockchain, it can be concluded that the application of blockchain to improve the overall trust in the supply chain and combating counterfeit and shoddy products has become a consensus in the industry. There are also many ideas for blockchain traceability. It has been implemented, and these theoretical and practical foundations have brought better help to our research.

2.2. Organic Food Supply Chain. Among the existing research results, the coordination between enterprises in the food supply chain and the green supply chain is most similar to the coordination of the organic food supply chain. Many scholars have conducted related research. Most of the coordination methods proposed by scholars mainly includes incentive coordination, cost coordination, and contract coordination. Rana and Paul [3] advocate an incentive mechanism. He believes that there will inevitably be some risks in the cooperative enterprises in the food supply chain. Therefore, some risks that may appear should be prevented and avoided. Among them, the use of incentive mechanisms is an excellent way to avoid risks. One of the means. Perlman et al. [39] conducted a theoretical and empirical analysis of the contractual cooperation between upstream and downstream suppliers and retailers in the food supply chain.

A large number of articles have studied the problem of profit coordination between manufacturers and retailers in the supply chain, and have designed a variety of coordination mechanisms to maximize the profits of the supply chain, but only a small number of articles have included the consumers who determine product sales in the model and considered the influence of consumer mentality factors even less. Segura et al. [40] found that bargaining power is the most important determinant of the relationship between core and upstream and downstream firms in the food supply chain, and the researchers studied the bargaining process between firms in the food supply chain by applying game bargaining theory. Denver et al. [41] studied 149 companies at the core of the supply chain, and pointed out that companies in large industries with high uncertainty have begun to pay attention to and implement guidance, education, evaluation, and guidance on green suppliers. Supervise activities to achieve vertical and horizontal expansion of the enterprise and improve the performance level of the enterprise. Paciarotti and Torregiani [42] proposed that the effect of pollution prevention in supply chain operation is closely related to the degree of cooperation between upstream and downstream enterprises in the supply chain. Carino et al. [43] believe that the bullwhip effect in the supply chain is obvious, and propose that if information sharing is used as a coordination incentive mechanism, the phenomenon of bullwhip effect in the supply chain can be effectively reduced, and the safety and quality problems in the food supply chain can be well solved and control. Torretta et al. [44] first discovered the different ways of undertaking supply chain enterprises, and on this basis, proposed two methods to achieve sustainable development of the supply chain, and proposed a method in which all members share environmental-related responsibilities. A large number of articles simplify the supply chain coordination problem to a two-player game model of a supplier and a retailer, and few articles study the game between the two groups of suppliers and retailers. In view of the deficiencies in the above studies, our paper will conduct further in-depth research. Haleem et al. [45] conducted an actual survey of a few manufacturing companies in the United States, and on this basis, proposed some supply chain systems to help companies establish how to coordinate with the environment within the system. Nakandala and Lau [46] put forward a specific method on how to use a reliable accountability system to improve the food safety factor. The research results show that contract management can improve the food safety factor in the food supply chain very well.

2.3. Supply Chain Contract. We will use cost-sharing and revenue-sharing contracts, so the research review will be more inclined to the relevant research status in this area. There are still many studies on the use of cost-sharing and revenue-sharing contracts to coordinate supply chains, which is suitable for the supply chain model that solves the uneven sharing of supply chain costs and the uncoordinated distribution of benefits, which is consistent with our research content. The introduction of blockchain technology will increase some additional costs, so we believe that revenue-sharing and cost-sharing contracts should be one of the preferred contracts for coordination of organic food supply chain contracts, and are also more suitable for solving problems in organic food supply chains and coordination issues.

The research on cost-sharing and revenue-sharing contracts is in-depth and extensive, and they are basically the coordination research applied to two-level and three-level supply chain models, including single contract coordination, as well as joint and improved contract coordination. For example, Dubey et al. [47] studied the contract coordination problem of the two-level supply chain of banks and e-commerce platforms, by introducing parameters such as effort level and cost, reputation information price and cost, and used game theory to analyze the final use of revenue-sharing and cost-sharing contracts to achieve supply chain coordination.

In addition, there are a number of top scholars who have made substantial contributions in their respective fields. Goli et al. [48] address a robust multiobjective multi-period aggregate production planning (APP) problem based on different scenarios under uncertain seasonal demand. According to the survey conducted by Ghoreishi et al. [49], optimal pricing strategy is one of the major policies for sellers or retailers to obtain its maximum profit. Goli et al. [50] address the multiobjective, multiproduct, and multi-period closed-loop supply chain network design with uncertain parameters, whose aim is to incorporate the financial flow as the cash flow and debts' constraints and labor employment under fuzzy uncertainty. Savku and Weber [51] study a stochastic optimal control problem for a delayed Markov regime-switching jump-diffusion model. Lotfi et al. [52] suggested a hybrid fuzzy and data-driven robust optimization for Resilience and Sustainable Health Care Supply Chain (RSHCSC) with VMI approach is appropriate for improving the inventory management system and tackling uncertainty and disruption in this situation. Tirkolaee et al. [53] identified the contributions of ML techniques in selecting and segmenting suppliers, predicting supply chain risks, and estimating demand and sales, production, inventory management, transportation and distribution, sustainable development (SD), and circular economy (CE). Kropat et al. [54] proposed a novel framework of semi-algebraic gene-environment networks. Khalilpourazari and Doulabi [55] showed that the offered robust model handles uncertainties more efficiently and finds solutions that have significantly lower costs and delivery time. Midya et al. [56] mainly focus on presenting an innovative study of a multi-stage multi-objective fixed-charge solid transportation problem (MMFSTP) with a green supply chain network system under an intuitionistic fuzzy environment.

Lin and He [57] studied the master-slave problem of the two-level supply chain of suppliers and e-commerce platforms by introducing several parameters, fresh-keeping effort level, and cost. The mixed contract of revenue-sharing and cost-sharing realizes the coordination of the supply chain. Jiang and Liu [58] studied the supply chain coordination problem of the three-level fresh food e-commerce supply chain of suppliers, distributors, and retailers through two variables of loss value and confidence level, and finally realized the supply chain through revenue-sharing contracts and discount contracts and coordination. Chang et al. [59] studied the supply chain coordination among the three stakeholders of e-commerce suppliers, third-party logistics companies, and community retail fresh stores, and introduced two variables, freshness preservation effort level and freshness, to define fresh food products. Finally, through game theory analysis, it can be seen that the supply chain is not coordinated, and the supply chain coordination is realized through revenue-sharing and preservation cost-sharing contracts. Dolgui et al. [60] study the coordination problem of two-level fresh food supply chain including suppliers and retailers, and use Stackberg game to analyze, and use cost universal contract to study whether it can make the supply chain coordinated, and finally, the numerical analysis verifies its effectiveness. Xiao et al. [61] proposed to add a reverse revenue-sharing contract to the closed-loop supply chain for coordination in view of the inconsistency in the closed-loop supply chain.

The research on cost-sharing and revenue-sharing contracts is still relatively abundant. Among them, cost-sharing contracts are mostly used when there are common costs in the supply chain, while revenue-sharing contracts are mostly used in conjunction with cost-sharing contracts which can achieve supply chain coordination.

In conclusion, first of all, we consider the method of quantitative analysis and research, and respectively, construct the game model under the blockchain and the traditional mode. We study the profit changes under the blockchain and the traditional mode, respectively. Each subject and the total profit are higher than the traditional model, and the cost threshold of applying the blockchain is found. Second, we describe the relationship between the authenticity rate of organic food and supply chain profit, and decentralized decision-making can lead to a decline in total supply chain profit. Finally, we design a cost-sharing and benefit-sharing contract, and conclude that the benefit-sharing and cost-sharing coefficients are within a certain range, which can facilitate coordination between organic food producers and retailers.

Table 1: Classification and survey of organic food supply chain.

Reference	Supply chain	Method	Contract	Objectives	Blockchain	Case study
[28]	Two-stage	Revenue-sharing	Single	Economic	—	Numerical Example (NE)
[24]	Two-stage	Cost-sharing	Single	Economic and IT costs enterprise	—	NE
[26]	Two-stage	Cost-sharing	Single	Economic and IT costs	—	NE
[30]	Two-stage	Return	Single	Economic	—	Offline supermarket
[27]	Two-stage	Quantity discount	Multi	Social enterprise	—	NE
[33]	Two-stage	Price subsidy	Single	Economic	—	NE
[37]	Two-stage	Quantity flexibility	Single	Economic	—	Offline supermarket
[29]	Two-stage	Return	Single	Environmental	—	NE
[25]	Two-stage	Return	Single	Social enterprise	-	NE
[36]	Two-stage	Revenue-sharing	Single	Economic	—	NE
[42]	Two-stage	Cost-sharing	Single	Environmental	—	NE
[38]	Two-stage	Return	Single	Social enterprise	—	NE
[45]	Two-stage	Quantity discount	Single	Economic	—	NE
[40]	Two-stage	Cost-sharing	Single	Economic and IT costs	—	NE
[47]	Two-stage	Price subsidy	Single	Economic	—	NE
This research	Two-stage + Two modes	Revenue-sharing + cost-sharing	Multi	Economy, organic field, society, and information technology	Application of blockchain	Enterprise chain

A more detail classification of the literature is presented in Table 1 with respect to six features including supply chain, method, contract, objectives, blockchain, and case study. The features related to the problem in the present study are presented in the last row of the table.

3. Problem Statement

We consider that many organic food manufacturers are both producers and distributors, and in the context of blockchain, the organic food supply chain does not need so many links to complete transactions. In order to facilitate analysis, we are considering including organic food. A two-tier supply chain model including food producers and retailers, where organic food producers are the leaders of this supply chain model, and retailers are followers, so our study is suitable for analysis by the Stackelberg game, where retailers decide the optimal price based on the wholesale price of organic food producers' selling price.

3.1. Assumptions and Notation List

(i) Organic food producers need to invest in additional costs to process and produce organic food, where $e\,(0 < e < 1)$ is the organic degree of the food [62].

(ii) We assume that the market demand function is of the form $Q^B = a - bp + \lambda e$, where a is the potential organic food market demand, b is the price sensitivity coefficient of organic food, p is the market price of organic food, and λe is the consumption [63].

(iii) The demand under the traditional and blockchain models is the retailer's order quantity D, so $Q = D$, our mathematical model use Q directly to analyze the order quantity, and no longer use D.

(iv) We assume that the application cost c_B and organic effort cost $ke^2/2$ of the blockchain are borne by the organic food manufacturer, the leader of the supply chain [64, 65].

Figure 1 describes the supply chain structure.

First, parameters and decision variables are defined in Table 2 as follows:

The supply chain decision-making problem is usually looked at from the perspectives of centralized and decentralized organization settings. In the following, we first study the decentralized decision model in the traditional model and compare it with the decentralized decision model in the blockchain model. We then study the centralized decision model in the blockchain model and find that the supply chain in the blockchain model is not optimal, arguing for the need to construct a coordination model.

3.2. Decentralized Decision-Making Model in Traditional Mode. First, we consider that, in the context of the traditional traceability model, the manufacturer is the leader of the supply chain and the retailer is the follower. In the traditional case, the consumer's demand function is of the form $Q^N = a - bp^N$. The organic food retailer purchases unit Q^N of organic food from the organic food manufacturer after clarifying the market demand. In the traditional traceability mode, there is a phenomenon of fake and inferior products, and the rate of genuine products is $\mu\,(0 < \mu < 1)$.

Then the profits of organic food producers and retailers can be obtained as follows:

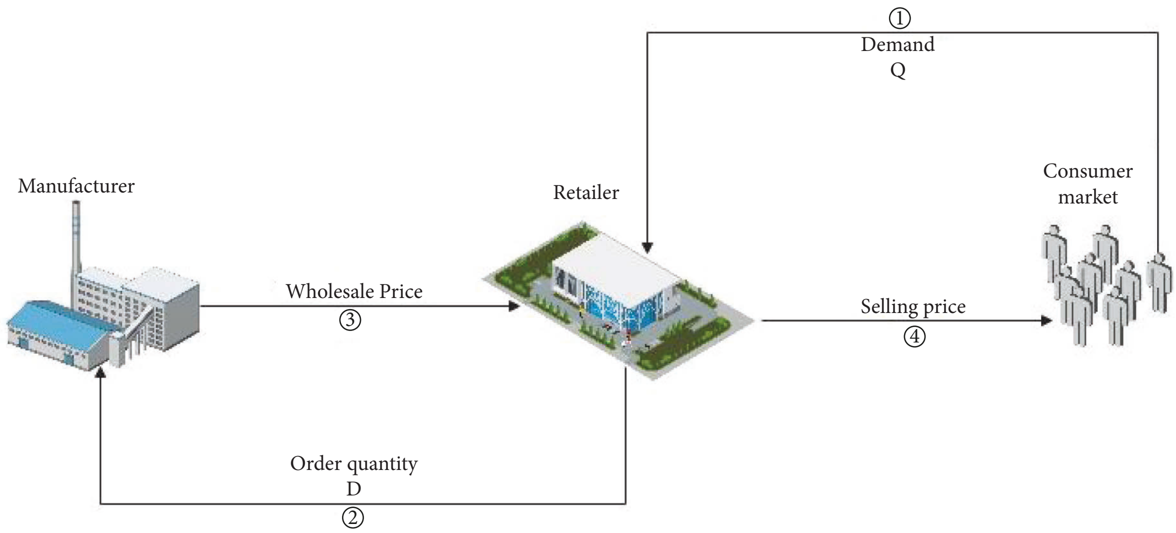

Figure 1: Model decision process.

Table 2: Notation list.

Variable	Description
Parameters	
k	Organic effort cost factor
p	Market price of organic food
w	Wholesale price per unit of organic food
μ	Authenticity rate of organic food
e	Degree of organic
λ	Organic preference
c_B	Application cost of blockchain technology
π_m	Organic food producer profit
π_r	Organic food retailer profit
π	Total supply chain profit
a	Potential organic food market demand
b	Price sensitivity of organic foods
c	Production cost per unit of organic food
Q	Consumer demand function
N	Traditional model
B	Blockchain model
Decision variables	
σ	Cost-sharing factor
ε	Revenue-sharing factor

$$\pi_m^N = \left(w^N - c\right)Q^N - \frac{k}{2}e^2, \tag{1}$$

$$\pi_r^N = \mu Q^N p^N - Q^N w^N. \tag{2}$$

Lemma 1. *Since $\partial^2 \pi_r^N/\partial (p^N)^2 = -2\mu b < 0$, $\partial^2 \pi_m^N/\partial (w^N)^2 = -b/\mu < 0$, there is an equilibrium decision, (p^{N*}, w^{N^*}, $\pi_m^{N^*}$, $\pi_r^{N^*}$, π^{N^*}) as follows:*

$$\begin{aligned} p^{N*} &= \frac{\mu a + bw^N}{2b\mu}, \\ w^{N^*} &= \frac{\mu a + bc}{2b}, \\ \pi_m^{N^*} &= \frac{(\mu a - bc)^2}{8\mu b}, \\ \pi_r^{N^*} &= \frac{(\mu a - bc)^2}{16\mu b}, \\ \pi^{N^*} &= \frac{3(\mu a - bc)^2}{16\mu b} \end{aligned} \tag{3}$$

the specific certification process is in Appendix.

3.3. Decentralized Decision-Making Model in the Context of Blockchain. We will analyze that in the context of blockchain, manufacturers and retailers are separate individuals under decentralized decision-making, and both manufacturers and retailers pursue the maximization of their own interests. At this point, the retailer wants to buy Q units of organic food from the producer, and the producer's wholesale price is w. Under the blockchain traceability mode, all information cannot be changed once it is on the chain, the information is symmetrical, and there is no counterfeiting. From here we will use the superscript B, which stands for the blockchain model. At this time $Q^B = a - bp^B + \lambda e$, the blockchain application cost c_B is borne by the organic food producer.

Then, the profits of organic food producers and retailers at this time can be obtained as follows:

$$\pi_m^B = \left(w^B - c\right)\left(a - bp^B + \lambda e\right) - c_B - \frac{k}{2}e^2, \quad (4)$$

$$\pi_r^B = \left(p^B - w^B\right)\left(a - bp^B + \lambda e\right). \quad (5)$$

The specific certification process is in Appendix.

Lemma 2. *Since* $\partial^2 \pi_r^B / \partial (p^B)^2 = -2b < 0$, $\partial^2 \pi_m^B / \partial (w^B)^2 = -b < 0$, *there is an equilibrium decision,* $(p^{B*}, w^{B*}, \pi_m^{B*}, \pi_r^{B*}, \pi^{B*})$ *as follows:*

$$\begin{aligned} p^{B*} &= \frac{a + \lambda e + bw^B}{2b}, \\ w^{B*} &= \frac{a + \lambda e + bc}{2b}, \\ \pi_m^{B*} &= \frac{(a + \lambda e - bc)^2}{8b} - c_B - \frac{k}{2}e^2, \\ \pi_r^{B*} &= \frac{(a + \lambda e - bc)^2}{16b}, \\ \pi^{B*} &= \frac{3(a + \lambda e - bc)^2}{16b} - c_B - \frac{k}{2}e^2. \end{aligned} \quad (6)$$

The specific certification process is in Appendix.

3.4. Comparison of Traditional Models and Models in the Context of Blockchain. We compare the retailer's profit, the supplier's profit, and the overall profit of the supply chain between the traditional model and the blockchain scenario, and draw the following propositions:

Proposition 1. *The profit of the retailer under the blockchain model is higher than that of the retailer under the traditional model.*

From Proposition 1, for organic food retailers, the adoption of blockchain is beneficial, at least more profitable than the traditional model.

The specific certification process is in Appendix.

Proposition 2. *To meet certain conditions, the profit of producers under the blockchain model can be higher than that of the traditional model.*

See Appendix for the specific certification process.

Proposition 3. *The application of blockchain can effectively eliminate the fake and shoddy organic food, improve the trust of organic food, and at the same time attract a part of consumer demand to buy organic food, which directly brings about an increase in revenue, from the overall profit of the supply chain. From a perspective, if the cost of blockchain is too high, it is not recommended for the supply chain to adopt blockchain for anti-counterfeiting traceability of organic food.*

The specific certification process is in Appendix.

Corollary 1. *When* $0 \le c_B \le c_B^E$, *after the application of blockchain technology, the total profit of the supply chain can be improved, where* $c_B^E = 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - k/2e^2$.

The specific certification process is in Appendix.

Corollary 1 finds the cost threshold of blockchain application, that is, within this threshold range, blockchain can improve the total profit of the supply chain and increase the stability of the organic food supply chain.

Corollary 2. *When* $c_B \ge c_B^E$, *after the blockchain is put into application, the total profit of the supply chain is less than that of the traditional model, where* $c_B^E = 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - k/2e^2$.

The specific certification process is in Appendix.

Corollary 2 states that when the cost of blockchain application is higher than this threshold, the overall profit of the supply chain will decline and will be lower than the traditional model. Therefore, the application of blockchain technology is not recommended at this time.

3.5. Centralized Decision-Making Model in the Context of Blockchain. Under centralized decision-making, the supply chain as a whole, organic food producers, and retailers will decide pricing for the entire supply chain to achieve the optimal profit level without the cost of ordering products.

Then the profit of the supply chain system can be obtained as follows:

$$\pi^B = \left(p^B - c\right)\left(a - bp^B + \lambda e\right) - c_B - \frac{k}{2}e^2. \quad (7)$$

Lemma 3. *Since* $\partial^2 \pi^B / \partial (p^B)^2 = -2b < 0$, *there is an equilibrium decision,* (p^{B**}, π^{B**}) *as follows:*

$$\begin{aligned} p^{B**} &= \frac{a + bc + \lambda e}{2b}, \\ \pi^{B**} &= \frac{(a - bc + \lambda e)^2}{4b} - c_B - \frac{k}{2}e^2. \end{aligned} \quad (8)$$

The specific certification process is in Appendix.

Obtained by comparison: $p^{B*} > p^{B**} = w^{B*}$. In other words, the sales price of organic food under decentralized decision-making is greater than that under centralized decision-making, and the sales price under centralized decision-making is equal to the wholesale price under decentralized decision-making.

Also in the context of blockchain, from the perspective of the total profit of the supply chain, when π^{B*} is compared in decentralized decision-making and π^{B**} in centralized decision-making, we get $\pi^{B*} < \pi^{B**}$. In other words, the total profit of the supply chain in decentralized decision-making is lower than that in centralized decision-making, which indicates that the supply chain profit does not reach the optimal state and Pareto efficiency when decentralized decision-making is used. At this time, the supply chain is not in the optimal state, so we consider using cost-sharing contracts for coordination.

3.6. Coordinating the Supply Chain

3.6.1. Cost-Sharing Contract Coordination under Decentralized Decision-Making in the Context of Blockchain. The blockchain-based organic food supply chain does not achieve Pareto efficiency in decentralized decision-making, and the supply chain is not optimal. Since the cost of blockchain is borne by the manufacturer, for retailers, they prefer to apply blockchain technology to eliminate fake and shoddy organic food, while retailers do not bear the cost of blockchain application and organic efforts costs, which in turn lead to supply chain imbalances. Therefore, we first adopt a cost-sharing contract to coordinate the organic food supply chain in the blockchain context, optimized as follows: organic food producers wholesale to retailers at a lower price w than the wholesale price in decentralized decision-making; at the same time, the retailer commits to bear a proportion σ of the blockchain cost c_B and the organic effort cost $ke^2/2$, which is the proportion that the producer bears $(1-\sigma)$. Producers and retailers share the cost of blockchain and organic efforts. The introduction of the subscript–CS indicates the state under the cost-sharing contract.

At this point, the profits of organic food producers and retailers under the cost-sharing contract can be obtained as follows:

$$\pi^B_{m-CS} = \left(w^B - c\right)\left(a - bp^B + \lambda e\right) - (1-\sigma)\left(c_B + \frac{k}{2}e^2\right), \quad (9)$$

$$\pi^B_{r-CS} = \left(p^B - w^B\right)\left(a - bp^B + \lambda e\right) - \sigma\left(c_B + \frac{k}{2}e^2\right). \quad (10)$$

Lemma 4. *Since $\partial^2\pi^B_{r-CS}/\partial(p^B)^2 = -2b < 0$, there is an equilibrium decision, $(p^{B***}, \pi^{B***}_{m-CS}, \pi^{B***}_{r-CS}, \pi^{B***}_{CS})$ as follows:*

$$\begin{aligned} p^{B***} &= \frac{a + \lambda e + bw^B}{2b}, \\ \pi^{B***}_{m-CS} &= (\sigma - 1)\left(c_B + \frac{k}{2}e^2\right) \leq 0, \\ \pi^{B***}_{r-CS} &= \frac{(a + \lambda e - bc)^2}{4b} - \sigma\left(c_B + \frac{k}{2}e^2\right), \\ \pi^{B***}_{CS} &= \frac{(a + \lambda e - bc)^2}{4b} - c_B - \frac{k}{2}e^2 = \pi^{B**}. \end{aligned} \quad (11)$$

The specific certification process is in Appendix.

In order to realize the coordination of supply chain, the necessary condition of cost-sharing contract is that the optimal sales price p^{B***} under the coordination of cost-sharing contract is equal to the optimal sales price p^{B**} under centralized decision-making, namely, $a + \lambda e + bw^B/2b = a + bc + \lambda e/2b$, which can be obtained through algebraic analysis. When $w^B = c$, $p^{B**} = p^{B***}$. At this time, the maximization of the profit of the supply chain is achieved, that is, under the cost-sharing contract, the overall profit of the supply chain can be optimized.

It can be seen that the total profit of the supply chain under the cost-sharing contract is equal to the total profit under the centralized decision-making. There are two purposes of supply chain coordination. First, to optimize the overall profit of the supply chain; second, to make the profits of manufacturers and retailers more than when the supply chain contract is not adopted. However, it can be seen from the analysis that the producer's profit $\pi^{B***}_{m-CS} \leq 0$ under the coordination of the cost-sharing contract is less than that without the contract. This shows that the cost-sharing contract can only optimize the total profit of the supply chain, while the profit of the manufacturer is mainly transferred to the retailer, which will reduce the profit of the manufacturer, which is mainly beneficial to the retailer. Obviously, it is not a win-win situation for the supply chain. Therefore, the cost-sharing contract cannot realize the coordination of the supply chain.

3.6.2. Analysis of Benefit-Sharing Cost-Sharing Contract Coordination under Decentralized Decision-Making in the Context of Blockchain. Although the cost-sharing contract can maximize the profit of the supply chain, the profit of the manufacturer has been significantly reduced, while the profit of the retailer has increased, which has not achieved a win-win situation for all the main bodies of the supply chain. However, due to the unbalanced distribution of profits between manufacturers and retailers, cost-sharing contracts will not be adopted in real economic activities. Therefore, we then consider the use of an improved cost-sharing contract for coordination, that is, on the basis of the original cost-sharing contract coordination, we propose to let the retailer's sales draw ε proportion to the manufacturer. The introduction of subscript-CSRS indicates the state under the combined contract of cost-sharing and benefit-sharing.

At this point, the profits of organic food producers and retailers under the hybrid contract of cost-sharing and revenue-sharing can be obtained as follows:

$$\pi^B_{m-\mathrm{CSRS}} = \left(w^B - c + \varepsilon p^B\right)\left(a - bp^B + \lambda e\right) - (1-\sigma)\left(c_B + \frac{k}{2}e^2\right), \quad (12)$$

$$\pi^B_{r-CSRS} = \left[(1-\varepsilon)p^B - w^B\right]\left(a - bp^B + \lambda e\right) - \sigma\left(c_B + \frac{k}{2}e^2\right). \quad (13)$$

Lemma 5. *Since $\partial^2\pi^B_{r-CSRS}/\partial(p^B)^2 = -2b(1-\varepsilon) < 0$, there is an equilibrium decision, $(p^{B****}, \pi^{B****}_{m-CSRS}, \pi^{B****}_{r-CSRS}, \pi^{B****}_{CSRS})$ as follows:*

$$p^{B****} = \frac{a+\lambda e}{2b} + \frac{bw^B}{2b(1-\varepsilon)},$$

$$\pi_{m-CSRS}^{B****} = \frac{\varepsilon(a+\lambda e-bc)^2}{4b} - (1-\sigma)\left(c_B + \frac{k}{2}e^2\right),$$

$$\pi_{r-CSRS}^{B****} = \frac{(1-\varepsilon)(a+\lambda e-bc)^2}{4b} - \sigma\left(c_B + \frac{k}{2}e^2\right), \tag{14}$$

$$\pi_{CSRS}^{B****} = \frac{(a+\lambda e-bc)^2}{4b} - c_B - \frac{k}{2}e^2.$$

From the analysis in the previous section, we know that supply chain coordination can only be achieved under the following conditions:

$$p^{B****} = \frac{a+\lambda e}{2b} + \frac{bw^B}{2b(1-\varepsilon)} = p^{B**} = \frac{a+bc+\lambda e}{2b}. \tag{15}$$

The specific certification process is in Appendix.

Through algebraic analysis, it can be obtained that when $w^B = c(1-\varepsilon)$, the formula is established, and the supply chain can maximize profits at this time.

In order to achieve a win-win situation and achieve a state of supply chain coordination, the following conditions must be met: $\pi_{m-CSRS}^{B****} \geq \pi_m^{B*}$ and $\pi_{r-CSRS}^{B****} \geq \pi_r^{B*}$. It can be seen from the coordination of supply chain, $(1-2\varepsilon)(a+\lambda e-bc)^2/ \quad 8b\sigma \leq c_B + k/2e^2$ and $c_B + k/2e^2 \leq (3-4\varepsilon)(a+\lambda e-bc)^2/\ 16b\sigma$.

The final results show that the revenue-sharing factor ε and the cost-sharing factor σ can be solved. When ε and σ meet the conditions, the organic food supply chain reaches a coordinated state.

3.7. Results and Discussion. We have established the relationship between blockchain input cost and market demand function by assuming the conditions and relevant parameter variables. Firstly, in the comparative analysis between the traditional situation model under decentralized decision-making and the model under blockchain scenario, we conclude that the benefit of applying blockchain is to eliminate counterfeit organic food and increase the sales profit of retailers. Next, the profit functions of suppliers and retailers under decentralized decision-making and the overall profit of the supply chain under centralized decision-making are then derived. Since the optimal pricing under decentralized decision is not equal to the optimal pricing under centralized decision model. According to the coordination theory of supply chain, the supply chain under decentralized decision model can easily fall into a dysfunctional state. We demonstrate that the supply chain is indeed in a disjointed state by comparing the profits under decentralized decision-making and centralized decision-making. Since the input costs of blockchain are mainly borne by suppliers, we first propose a cost-sharing contract to coordinate the supply chain. Through the analysis, it is clear that a single cost-sharing contract cannot bring the supply chain to a coordinated state, so we consider introducing a revenue-sharing contract and consider allowing the retailer to give a portion of the revenue to the supplier. We find that when the cost-sharing factor and revenue-sharing factor vary within a certain range, the supply chain achieves a coordinated state. This suggests that a combination of revenue-sharing and cost-sharing contracts can lead to a coordinated organic food supply chain in a blockchain scenario. This section focuses on the derivation and analysis of algebraic equations, and the specific numerical arithmetic analysis is in the following, where we validate the previous findings.

4. Case Study

The Shanghai Dynamic Information System Co. Ltd., Shanghai, China, is considering the implementation of this newly proposed portfolio optimization solution. The lack of an accurate grasp of the organic food market and the pricing of the application costs of blockchain technology to make the right decisions was one of the main problems of this company, which led to high link costs. The ensuing high risk and lack of reward in producing organic food in the traditional model forced the managers of the food suppliers to optimize for the future to better cater to the consumer market.

The Shanghai Business Information Center released the results of a special questionnaire survey on the Shanghai organic food consumer market at the "China International Organic Food Expo," which opened in May. The survey interviewed more than 600 consumers who had organic food consumption experience and basically painted a picture of the characteristics and consumption preferences of the Shanghai organic food market. According to the survey, female consumers with a bachelor's degree or above, married with children, and an annual family income of 120,000–250,000 RMB are the main consumer group in the organic food market, accounting for 59%. The consumption rate of vegetables, grains, and fruits topped the list, and the popularity of other organic foods, including meat products, dairy products, and aquatic products, reached a high level. It is worth mentioning that the characteristics of cross-category consumption of the middle-aged and elderly groups are very obvious. High frequency of purchase and high price tolerance highlight the degree of consumer recognition. In terms of purchase frequency, the proportion of respondents who buy organic food once every two or three days is 44%, and those who buy every week is 36%, totaling 80%. Single consumption of more than 100 yuan accounted for 37%, more than 200 yuan accounted for 28%, a total of 65%, indicating that people who have experienced consumption of organic food to achieve a high level of recognition and loyalty, the overall health and durability of the market is strong. Supermarket chains are still the mainstream sales channels for organic food, and the scale of online consumption is expanding rapidly. The survey shows that 79.5% and 78.2% of consumers have purchased organic food in hypermarkets and fresh food supermarkets, respectively, substantially higher than other formats. 37.0% of consumers have purchased from online stores. The standardization of organic food, the ease of ordering of cold chain logistics, and maturation are driving the rapid expansion of online channel sales. The pursuit of health and quality of life is the motivation for these consumers to buy. When asked about the motivation for buying organic food, 77.5% and 73.2% of the respondents chose "health" and "quality assurance," which have become the golden sign and core competitiveness of organic food to expand market share. When selecting organic food, 70%, 67%, and 65% of the respondents will focus on "freshness," "safety," and "nutrition," respectively. The lowest concern for "packaging," only 27%, from a side to reflect the proportion of self-consumption reached a considerable level. Organic food is gradually integrated into people's lives. More than half of the respondents could not distinguish or incorrectly distinguish between organic food, green food, and other professional concepts. In addition, when asked about the use of chemical fertilizers in the organic food growing process, respondents also showed "confusion," indicating that the concept of organic food and standards to be standardized and popularized. According to the survey, the overall satisfaction of respondents with the organic food market is high, with 21% and 58% of respondents being "satisfied" and "relatively satisfied," respectively. When asked to improve the expected aspects, "industry standard management," "commodity richness," and "commodity quality" three top, were selected by the rate of 58.7%, 54.8%, and 51.5%, respectively.

In the traditional organic food supply chain model, starting from the organic food raw material planting, through the organic food processing enterprises for production, and then through the wholesale market, supermarkets, and other large intermediaries or retailer to deliver the finished organic food to the hands of organic food consumers. With the development of the Internet of Things, Internet, big data, cloud computing, and other information technology, organic food processing enterprises and upstream farmers and downstream retail merchants to cooperate and dependent with each other. Information sharing has been higher than before, but still not enough, and the real supply chain member enterprises should be connected together to form a synergistic and competitive whole.

A comparative analysis of the organic food supply chain traceability system in the context of traditional IoT technology and blockchain technology summarizes the advantages of adopting blockchain technology. Blockchain technology meets the current urgent needs of the industry. Blockchain is an innovative application mode of computer technologies such as cryptographic algorithms, consensus mechanisms, and distributed storage, and the combination of blockchain technology and traceability systems can improve the shortcomings of traditional organic food quality and safety traceability systems. The security of data is high in the blockchain context. The blockchain context is conducive to the supervision and pursuit of responsibility and the fight against counterfeiting.

Next, the profit prediction brought by blockchain technology to each member of the organic food supply chain is run in MATLAB R2021, implemented using a PC (CPU Core i7 and 16G RAM). The results obtained in the optimization are presented in the next section. The organic food quality and safety traceability system in the context of blockchain technology has many advantages, but the development of promotion in blockchain also encounters some obstacles, which makes it difficult to promote the blockchain traceability system. On the one hand, without informationization in the whole process of organic food supply chain circulation, there is no way to put information collection on the chain. On the other hand, some large enterprises recognize the many benefits brought by blockchain and actively adopt it, while Shanghai Dynamic Information System Co., Ltd. adopts blockchain because of its complicated technology, large investment, relatively high cost, and serious old-fashioned thinking, and the adoption of blockchain brings a relatively big impact on the traditional centralized operation mode, which is also an important reason to prevent SMEs from adopting blockchain. With the development and promotion of blockchain technology, when SMEs gradually realize the benefits brought by blockchain, the full-scale promotion and application of blockchain will become a reality.

5. Numerical Analysis

With the previous theoretical foreshadowing and formula derivation basis, we will use an example to conduct an empirical analysis of the previous research results. In cooperation with Shanghai Energy Information System Co., Ltd. to conduct field research and analysis, the organic food under the blockchain traceability scenario eliminates counterfeit organic food, significantly improves the trust and sales of products, and the cost of blockchain is not high. Therefore, this chapter will verify the relevant results of the investigation by assigning them. From the previous model derivation, it can be seen that several parameters that can be assigned in the model include: a, k, b, c, c_B, e, μ, and λ. Considering the reality, assign these parameters as follows: $a = 110, k = 20, b = 4, c = 1, c_B = 1, e = 0.9, \mu = 0.5, \lambda = 50$, and $e, \varepsilon, \sigma \in [0, 1]$.

5.1. The Impact of Organic Food Authenticity Rate μon Supply Chain Profits. In the context of the traditional traceability model, $Q^N = 110 - 4p^N$, the genuine rate of organic food $\mu = 0.5$.

At this point, the producer's profit is $\pi_m^N = (w^N - 1)(110 - 4p^N) - 8.1$. The retailer's profit is $\pi_r^N = 0.5(110 - 4p^N)p^N - (110 - 4p^N)w^N$. The optimal wholesale price, optimal sales price, optimal profit of producers and retailers, and total supply chain profit of organic food can be solved as follows: $w^{N^*} = 7.38$, $p^{N*} = 34.88$, $\pi_m^{N^*} = 162.56$, $\pi_r^{N^*} = 81.28$, and $\pi^{N^*} = 243.84$.

When the value of μ changes, it will have an impact on the total profit of organic food manufacturers, retailers, and supply chains as shown in Table 3.

Figure 2 shows that (1) with the increase in the authentic rate μ of organic food, the overall profits of manufacturers, retailers, and supply chains will increase. (2) This shows that

Table 3: The impact of organic food authenticity rate μ on supply chain profits.

μ	π_m^N	π_r^N	π^N
0.1	15.31	7.66	22.97
0.3	87.60	43.80	131.4
0.5	162.56	81.28	243.84
0.7	237.90	118.95	356.85
0.9	313.37	156.68	470.05

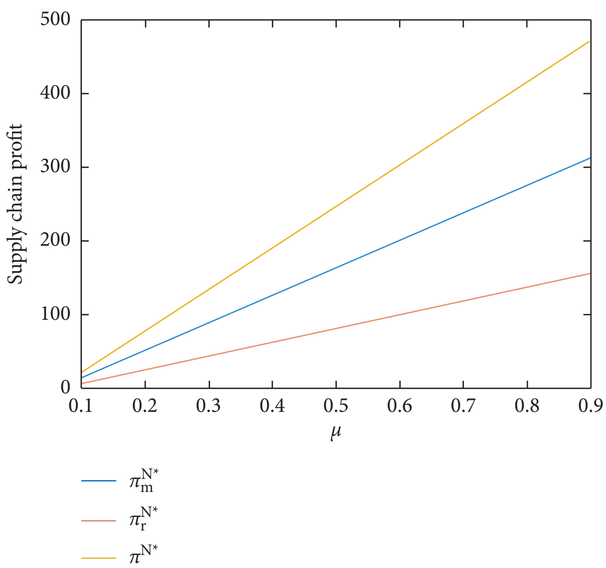

Figure 2: The impact of the genuine product rate μ on the profit of the supply chain.

even in the traditional supply chain model, increasing the genuine rate of organic food can make the supply chain more profitable. (3) Under the traditional model, it is not easy to improve the genuine rate of organic food and make consumers trust organic food.

5.2. The Impact of Organic Degree e on Supply Chain Profits. In the context of blockchain, the genuine rate of organic food is $\mu = 1$, and there is basically no fake and shoddy organic food, $e = 0.9$.

At this point, the producer's profit is $\pi_m^B = (w^B - 1)(-4p^B + 155) - 9.1$. The retailer's profit is $\pi_r^B = (p^B - w^B)(-4p^B + 155)$. The optimal wholesale price, the optimal selling price, the optimal profit of the producer and the retailer, and the total profit of the supply chain can be obtained as $w^{B*} = 19.88$, $p^{B*} = 29.32$, $\pi_m^{B*} = 703.43$, $\pi_r^{B*} = 356.27$, and $\pi^{B*} = 1059.70$.

By comparison, we can see that $\pi_m^{B*} > \pi_m^{N^*}$, $\pi_r^{B*} > \pi_r^{N^*}$, and $\pi^{B*} > \pi^{N^*}$, the overall profits of manufacturers, retailers, and supply chains are more in the context of blockchain, which shows that the adoption of blockchain can bring about an increase in the profits of all links in the supply chain, and blockchain technology is worthwhile. Adopted and promoted.

Figure 3 shows that (1) the total profit of organic food producers, retailers, and supply chains under the blockchain model is significantly higher than that of the traditional model. (2) We study and analyze the relationship between the organic degree e and the profit of the supply chain, and we will get the optimal profit of the manufacturer, the retailer, and the whole supply chain under different e conditions. As the organic level e increases, the profits of the main members of the supply chain also increase.

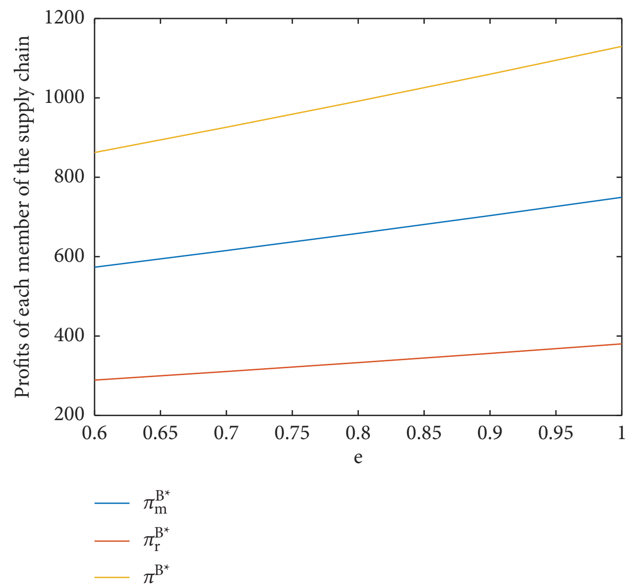

Figure 3: The impact of e on supply chain profits.

Table 4: The impact of organic degree e on supply chain profits.

e	μ	π_m^B	π_r^B	π^B
0.6	1	573.40	289.00	862.40
0.7	1	615.38	310.64	926.02
0.8	1	658.73	333.06	991.79
0.9	1	703.43	356.27	1059.7
1.0	1	749.50	380.25	1129.75

Comparing Tables 4 with 3, we can conclude that even with the same authenticity rate and the same organic level, the profit gained from adopting blockchain is always higher than that of not adopting blockchain, This also fully proves that the blockchain should be adopted.

In order to more intuitively express the relationship between the change of e and the change of supply chain profit, MATLAB software is used for simulation as shown in Figure 3.

5.3. The Impact of Cost-Sharing and Revenue-Sharing Factors on Supply Chain Profits. We consider using an improved cost-sharing contract for further coordination, and on the basis of the original cost-sharing contract, let the retailer give ε proportion of the revenue to the manufacturer. At this point, the profit function of the manufacturer and the retailer is $\pi_{m-\text{CSRS}}^B = (w - 1)(155 - 4p) - 9.1(1 - \sigma) + \varepsilon p(155 - 4p)$, $\pi_{r-CSRS}^B = [(1 - \varepsilon)p - w](155 - bp) - 9.1\sigma$. Figure 4 shows

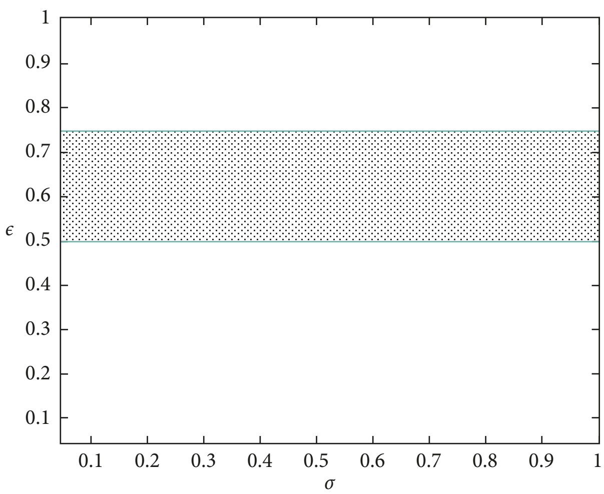

FIGURE 4: ε and σ value relationship.

that (1) supply chain coordination can be achieved when the benefit-sharing factor ε and the cost-sharing factor σ satisfy conditions. (2) In the interval of $\varepsilon \in [0.494, 0.750]$, $\sigma \in [0, 1]$; in other words, the value range is the shaded part in the figure. (3) The combined contract of revenue-sharing and cost-sharing can achieve Pareto improvement, the organic food supply chain based on blockchain can be coordinated, and all entities in the supply chain can achieve optimal profits.

According to the current research status of supply chain contracts, the way of benefit distribution and risk sharing between suppliers and retailers, and the way of order acquisition, supply chain contracts can be divided into the following main types: pricing contracts, repurchase contracts, quantity flexibility contracts, and revenue-sharing contracts. Pricing contract means that the retailer decides the order quantity according to the market demand and wholesale price, the supplier and the manufacturer organize the production according to the retailer's order quantity, the retailer is responsible for handling the inventory products, and the retailer forecasts the product sales. Therefore, the supplier's profit is determined in this contract, and the retailer fully assumes the risk of market uncertainty. This type of contract emerged earlier and is well developed and is widely used in a number of fields. Such a supply chain contract is very effective in markets with multiple (or infinite) consecutive sales cycles. This has now been built upon in the form of price protection contracts, where the supplier compensates the retailer for unsold goods when the wholesale price of the product falls over the product's life cycle. This type of covenant is often used in the field of personal computers and cell phones.

A buy-back contract is one in which the supplier buys back the remaining merchandise at the end of the sales season at a certain price, and the retailer can decide for itself whether to return all of the merchandise, with the supplier forecasting product sales. The supplier and the retailer share the risk of market uncertainty. In addition, this strategy also affects consumers, because before the emergence of this supply-land contract, retailers usually used discount promotions to dispose of surplus goods, and suppliers worry that this approach will affect the status of their brands in the minds of consumers, and damage their product brands, especially in certain limited high-priced goods. Some scholars fear that this behavior will harm the supplier's interests and ultimately lead to the nonviability of such contracts, but research shows that the supplier's interests instead rise much higher as a result, because the number of orders from retailers is often irrational under the incentive of such contracts. The repurchase contract is one of the most convenient contracts to coordinate the supply chain because of its ease of implementation between suppliers and retailers and is naturally a hot topic of research. This contract has also given rise to other types of contracts, such as the sales rebate contract, in which the retailer receives a rebate from the supplier for each additional item sold after a certain number of sales, in essence giving the retailer a direct incentive to increase sales. It also provides an incentive for the retailer to increase the order quantity and further improve the system performance. Buy-back covenants are often applied in seasonal commodity markets.

Quantity flexibility contracting is where the retailer books a portion of the product prior to the start of the selling season, the supplier organizes production accordingly, and the retailer, having obtained a firm market demand, can determine the final purchase volume within the quantity of product that the supplier can provide to obtain the expected revenue. Under the quantity elasticity contract approach, two fluctuation limits are imposed: one is the maximum fluctuation ratio per order period, and the supplier is then obliged to meet the maximum upper limit of purchase quantity to prevent losses caused by sellers increasing the order quantity and resulting in supply chain shortages; the other is the minimum lower limit of product quantity that retailers must purchase to prevent sellers overestimating demand and resulting in supply chain overcapacity. Under these two constraints, a higher retailer order quantity maximizes supply chain benefits and reduces the impact caused by the dual marginal effects of suppliers and retailers. The purpose of quantity flexibility contracts is to make buyers and sellers share the risk or benefits, and to induce retailers to carefully forecast demand and plan order quantities. Quantity elasticity contracts increase the average quantity of goods purchased by the retailer, incentivize the retailer to try to forecast market demand to increase their desired profitability, and ultimately have the potential to increase the overall effectiveness of the supply chain. Such covenants are widely used in the electronics and computer fields. It is widely used by large companies such as IBM.

One problem that is unavoidable in all of the above supply chain contracts is that when the initial wholesale price is too high, the producer will not be able to gain enough benefit from a lower number of orders from the retailer, and if the wholesale price is lowered in order to increase the number of orders, it is equally likely to harm the benefits on production. Revenue-sharing contracts are designed to resolve this conflict. In a revenue-sharing contract, the retailer delivers a percentage of the sales revenue to the manufacturer in order to obtain a lower wholesale price. This

Table 5: Advantages and disadvantages of the proposed method versus the traditional method.

	RS-CS	Pricing contract	Repurchase deed	Quantity flexibility contract
Advantages	Wide range of applications and easy supply chain coordination	Effective in markets with multiple consecutive sales cycles	Suppliers and retailers share the risk of market uncertainty	Buyer and seller share the risk or share the benefits
Disadvantages	A little complicated	The supplier's profit is fixed	Retailers are often irrational in their order numbers	Retailers have a minimum purchase volume

mechanism not only provides an incentive for the retailer to order more products at a lower price, but also ensures that the manufacturer's interests are not lost and that all parties in the supply chain are coordinated. In this contract, both parties share the market risk and the expectation of market sales. However, the revenue-sharing contract cannot be considered the best form of supply chain contract. It also has certain limitations, mainly in two aspects: on the one hand, it requires the seller to detect the buyer's revenue, thus increasing the overhead; on the other hand, because revenue-sharing reduces the buyer's marginal profit, it drives the buyer to promote the sale of competing goods from other suppliers that do not have a sharing contract. Such contracts emerged with great success in the impression industry at the end of the last century, and were then rapidly extended to other industries.

In view of the limitations of single revenue-sharing contracts, cost-sharing contracts were introduced on top of revenue-sharing contracts. Cost-sharing contracts are mostly used when there are common costs in the supply chain, while revenue-sharing is mostly used in conjunction with cost-sharing contracts to achieve supply chain coordination more easily. In this study, we have to consider the cost of blockchain, so by reading a lot of related literature, we can conclude that the use of revenue-sharing and cost-sharing contracts is applicable for this study. The supplier and the retailer share a percentage of the cost, while allowing the retailer to put up a percentage of the revenue to the supplier. In reality, a single revenue-sharing contract can hardly solve the practical problems faced in the supply chain, so a combination of revenue-sharing and cost-sharing contract is designed to coordinate and thus solve the problem of supply chain coordination. In addition, this proposed combination contract is slightly more complex in application compared to the traditional single contract.

The advantages and disadvantages of the combined revenue-sharing and cost-sharing contract proposed in this study are compared with other traditional single contracts in Table 5.

6. Managerial Insights and Practical Implications

To a certain extent, our research results can provide a theoretical reference for the coordinated management of organic food supply chains in the blockchain context. For organic food supply chains that adopt blockchain for traceability, a combination of benefit-sharing and cost-sharing contracts can be introduced to achieve supply chain coordination. It also has some reference value for enterprises that have not yet applied blockchain. At the same time, many agricultural products have already applied blockchain for traceability, and our research results and theories have some guidance for the coordinated supply chain management of other brands of agricultural products in the blockchain context.

Driven by both national policies and the demand of the organic food industry, many organic food companies will also start to gradually adopt blockchain for traceability to solve the distrust problem existing between supply chains, promote supply chain unity and collaboration, and improve supply chain performance in order to achieve supply chain coordination and drive the organic food industry to continue to move forward. Our findings have practical guidance for studying the coordination of organic food supply chains in a blockchain context.

Through our research results, it is recommended that organic food enterprises that have not yet applied blockchain traceability respond to the national call and meet the industry demand by actively adopting blockchain for the full traceability of organic food, protecting the information security of organic food, maintaining the brand image of organic food, establishing trust between the upstream and downstream supply chains, eliminating the inflow of fake and shoddy organic food into the supply chain, and improving the solidarity and collaboration between supply chains. Nowadays, more and more organic food companies are applying blockchain for traceability. For the coordinated management of organic food supply chain in the context of blockchain, we suggest introducing a combination of benefit-sharing and cost-sharing contracts, so that the supply chain can achieve optimal and win-win results.

7. Conclusions and Outlook

In recent years, the organic food supply chain has always had the pain point of counterfeiting and shoddy, resulting in distrust between the upstream and downstream of the supply chain, thus affecting the cooperation and coordination of the supply chain. Under the premise that blockchain technology is being promoted and applied, the introduction of blockchain can reshape the trust between the upstream and downstream of the organic food supply chain, improve the efficiency of collaboration between supply chains, and eliminate counterfeit and shoddy products. On this basis, we propose a research on contract coordination of organic food supply chain based on blockchain technology. In the context of blockchain, the coordination of organic food supply chain is studied, and appropriate contracts are introduced to coordinate the supply chain, so that the supply chain can reach the optimal state of coordination.

What we build is a secondary supply chain model composed of manufacturers and retailers. With the background of blockchain, we conduct research on the coordination of supply chains. We establish the supply chain model under the traditional model and the blockchain traceability scenario, introduce the organic degree of food, establish its relationship with market demand and blockchain input cost, and then use the Stackelberg game to carry out analysis. By comparing the traditional model under decentralized decision-making and the model under the blockchain context, it is found that the adoption of blockchain will increase the profit of retailers, which is also in line with the actual situation. There is basically no fake and shoddy organic food in the blockchain context, and it is very beneficial for retailers to use blockchain technology to trace the origin of organic food. Secondly, by studying the total profit of the supply chain under the centralized decision-making of the supply chain under the blockchain scenario, it is proved that the supply chain under the decentralized decision-making has not reached the optimal state, so further coordination is needed to make the supply chain optimal. Therefore, we first consider the introduction of cost-sharing contracts to coordinate the supply chain. The results show that under the cost-sharing contract, the organic food supply chain can maximize the profit of the supply chain, but the profit of the producer is less than that without contract coordination. A single cost-sharing contract cannot make the supply chain achieve coordination. Adding a revenue-sharing contract to the original cost-sharing contract, that is, considering allowing organic food retailers to share a part of the revenue with the manufacturer on the basis of the cost-sharing contract. The research results show that when the cost-sharing factor and the revenue-sharing factor are in specific when changing the range of organic food supply chain, it is possible to achieve a coordinated state of organic food supply chain, which is also an important conclusion of our research.

The results of this research and managerial insights are as follows:

(1) The increase in the genuine rate of organic food under the traditional model will bring higher profits to the supply chain (c.f. Table 3; Figure 2). This shows that even in the traditional supply chain model, increasing the genuine rate of organic food can make the supply chain more profitable.

(2) The adoption of blockchain can not only improve the genuine rate of products and combat counterfeit and shoddy organic food, but also the increase in trust in the context of blockchain will attract some consumers to buy organic food, bringing additional benefits to the supply chain.

(3) The total profit of organic food producers, retailers, and supply chains under the blockchain model is significantly higher than that of the traditional model. As the organic level increases, the profits of the main members of the supply chain also increase (c.f. Table 4; Figure 3).

(4) Comparing Tables 4 with 3, we can conclude that even with the same authenticity rate and the same organic level, the profit gained from adopting blockchain is always higher than that of not adopting blockchain, This also fully proves that the blockchain should be adopted.

(5) Supply chain coordination can be achieved when the benefit-sharing factor and the cost-sharing factor satisfy the conditions. The combined contract of revenue-sharing and cost-sharing can achieve Pareto improvement, the organic food supply chain based on blockchain can be coordinated, and all entities in the supply chain can achieve optimal profits (c.f. Figure 4).

The uncertainty of demand in the organic food supply chain and the costs of other aspects have not been taken into account, which will be improved in follow-up research. The source of the blockchain data is not considered fraudulent. Although the information already on the blockchain is real and cannot be tampered with, the source of the data cannot be fraudulently avoided. If the data itself is false, the blockchain cannot identify and prevent it. How to ensure the authenticity of source data is also one of the research directions of blockchain applications in the future. On the premise that blockchain technology is being vigorously promoted and applied, the introduction of blockchain can reshape the trust between upstream and downstream of the organic food supply chain, improve the cooperation efficiency between supply chains, and eliminate fake and shoddy products. Finally, we suggest that organic food enterprises actively adopt blockchain technology, which can lead to an increase in the profits of all links of the supply chain. Blockchain is worthy of adoption and promotion. In conclusion, it should be noted that the analysis in this study will help decision makers to choose the most appropriate option among the possible solutions based on their criteria. This proposed framework can also be extended in various cases where profits are out of balance in the organic food supply chain, such as safety and value gain.

Appendix

Proof of Lemma 1. Under the decentralized decision-making of the traditional supply chain, organic food producers and retailers each pursue the maximization of profits. Therefore, from the perspective of maximizing the profits of each member of the supply chain, we obtain $\partial\pi_r^N/\partial p^N = \mu(a-2bp^N)+bw^N$ and $\partial^2\pi_r^N/\partial(p^N)^2 = -2\mu b<0$. Therefore, there is an optimal solution for π_r^N, and the reverse induction method is used to solve it, so that $\partial\pi_r^N/\partial p^N = 0$, the optimal sales price $p^{N*} = \mu a + bw^N/2b\mu$ is obtained. Substituting p^{N*} into equation (1), which takes its second partial derivative with respect to w^N, we obtain

$\partial^2\pi_m^N/\partial(w^N)^2 = -b/\mu < 0$, where π_m^N is concave in w^N. Solving the first-order condition $\partial\pi_m^N/\partial w^N = 0$ for w^N, we obtain $w^{N^*} = \mu a + bc/2b$. Substituting both p^{N*} and w^{N^*} into equations (1) and (2), we obtain $\pi_m^{N^*} = (\mu a - bc)^2/8\mu b$, $\pi_r^{N^*} = (\mu a - bc)^2/16\mu b$, and $\pi^{N^*} = 3(\mu a - bc)^2/16\mu b$. □

Proof of Lemma 2. From the perspective of maximizing the profits of each member of the supply chain, we obtain $\partial^2\pi_r^B/\partial(p^B)^2 = -2b < 0$, where π_r^B is concave in p^B. Solving the first-order condition $\partial\pi_r^B/\partial p^B = 0$ for p^B, we obtain $p^{B*} = a + \lambda e + bw^B/2b$. Substituting p^{B*} into equation (4), which takes its second partial derivative with respect to w^B, we obtain $\partial^2\pi_m^B/\partial(w^B)^2 = -b < 0$, where π_m^B is concave in w^B. Solving the first-order condition $\partial\pi_m^B/\partial w^B = 0$ for w^B, we obtain $w^{B*} = a + \lambda e + bc/2b$. Substituting both p^{B*} and w^{B*} into equations (4) and (5), we obtain $\pi_m^{B*} = (a + \lambda e - bc)^2/8b - c_B - k/2e^2$, $\pi_r^{B*} = (a + \lambda e - bc)^2/16b$, $\pi^{B*} = 3(a + \lambda e - bc)^2/16b - c_B - k/2e^2$. □

Proof of Proposition 1. Based on Lemmas 1 and 2. By subtracting the retailer's profit under the blockchain model from the retailer's profit under the traditional model, we get $\pi_r^{B*} - \pi_r^{N^*} = \mu(a + \lambda e - bc)^2 - (\mu a - bc)^2/16\mu b$.

When $\mu = 1$, the minimum value is obtained, where the minimum value is greater than 0, that is, $\pi_r^{B*} - \pi_r^{N^*} > 0$ is always established, so $\pi_r^{B*} > \pi_r^{N^*}$ is always established. For retailers, the adoption of blockchain is beneficial. The profit of retailers under the blockchain model is always greater than that of retailers under the traditional model, which is proved. □

Proof of Proposition 2. Based on Lemmas 1 and 2. Subtracting the producer's profit under the blockchain with the producer's profit under the traditional model, we get $\pi_m^{B*} - \pi_m^{N^*} = \mu(a + \lambda e - bc)^2 - (\mu a - bc)^2/8\mu b - c_B - k/2e^2$. This equation is greater than 0, which depends on the demand gain brought by the organic preference of consumers and the application cost of blockchain and the additional green effort cost of producers. □

Proof of Proposition 3. Based on Lemmas 1 and 2. Subtracting the total supply chain profit π^{B*} under the blockchain model and the total supply chain profit π^{N^*} under the traditional model, we get $\pi^{B*} - \pi^{N^*} = 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - c_B - k/2e^2$.

The total profit of the supply chain under the blockchain model is higher than the traditional situation, depending on the relationship between c_B, k, λ, and e. □

Proof of Corollary 1. Based on Proposition 3. To improve the total profit of the supply chain after applying the blockchain, in other words $\pi^{B*} \geq \pi^{N^*}$, we get $3(a + \lambda e - bc)^2/16b - c_B - ke^2/2 > 3(\mu a - bc)^2/16\mu b$, $c_B \leq 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - ke^2/2$. □

Proof of Corollary 2. Based on Proposition 3. Similar to Proofs of Corollary $1\pi^{B*} \leq \pi^{N^*}$, after simplification, we get $c_B \geq 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - ke^2/2$. □

Proof of Lemma 3. Under the centralized model, organic food producers and retailers are regarded as one decision-making organization. Therefore, from the perspective of maximizing the profit of the supply chain system, we obtain $\partial^2\pi^B/\partial(p^B)^2 = -2b < 0$, where π^B is concave in p^B. Solving the first-order condition $\partial\pi^B/\partial p^B = 0$ for p^B, we obtain $p^{B**} = a + bc + \lambda e/2b$. Substituting p^{B**} into the overall supply chain profit π^B, we get that under centralized decision-making, the optimal total supply chain profit is $\pi^{B**} = (a - bc + \lambda e)^2/4b - c_B - ke^2/2$. □

Proof of Lemma 4. Solving equation (10) for the second partial derivative with respect to p^B, we obtain $\partial^2\pi_{r-CS}^B/\partial(p^B)^2 = -2b < 0$, where π_{r-CS}^B is concave in p^B. Solving the first-order condition $\partial\pi_{r-CS}^B/\partial p^B = 0$, for p^B, we obtain $p^{B***} = a + \lambda e + bw^B/2b$ and $w^{B***} = c$,

Substituting both p^{B***} and w^{B***} into equations (9) and (10), we obtain $\pi_{m-CS}^{B***} = (\sigma - 1)(c_B + ke^2/2) \leq 0$, $\pi_{r-CS}^{B***} = (a + \lambda e - bc)^2/4b - \sigma(c_B + ke^2/2)$, $\pi_{CS}^{B***} = (a + \lambda e - bc)^2/4b - c_B - ke^2/2 = \pi^{B**}$. □

Proof of Lemma 5. Solving equation (13) for the second partial derivative with respect to p^B, we obtain $\partial^2\pi_{r-CSRS}^B/\partial(p^B)^2 = -2b(1 - \varepsilon) < 0$, where π_{r-CSRS}^B is concave in p^B. Solving the first-order condition $\partial\pi_{r-CSRS}^B/\partial p^B = 0$ for p^B, we obtain $p^{B****} = a + \lambda e/2b + bw^B/2b(1 - \varepsilon)$ and $w^{B****} = c(1 - \varepsilon)$. Substituting both p^{B****} and w^{B****} into equations (12) and (13), we obtain $\pi_{m-CSRS}^{B****} = \varepsilon(a + \lambda e - bc)^2/4b - (1 - \sigma)(c_B + k/2e^2)$, $\pi_{r-CSRS}^{B****} = (1 - \varepsilon)(a + \lambda e - bc)^2/4b - \sigma(c_B + k/2e^2)$, $\pi_{CSRS}^{B****} = (a + \lambda e - bc)^2/4b - c_B - k/2e^2$. □

Data Availability

The data used to support the findings of this paper are included within the article (Numerical Analysis section).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Strategic Analysis of the Recycler considering Consumer Behavior Based on E-Platform Recycling

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Internet + platform recycling is a new model of recycling that provides more ways to recycle WEEE. Considering consumers' preference for channels, we construct a single-channel reverse supply chain model (Model-S) and two dual-channel reverse supply chain models (Model-DU and Model-DD) consisting of a recycler and an e-platform and consider the unified pricing and differentiated pricing strategies in the dual-channel models. By solving the optimal decisions of members using game theory, we innovatively investigate the influence of channel competition and consumer behavior on e-platform recycling and provide a theoretical basis for recyclers to develop pricing strategies in different situations. We find that it is beneficial for the recycler to build its own channel and adopt the differentiated price strategy (Model-DD); more WEEE also can be recycled in this model. However, the e-platform prefers Model-S or Model-DU, which depends on the consumers' preference and the disposal revenue of WEEE. In addition, consumers' preference for e-platform is good for them but harmful for the recycler and has a negative impact on recycling quantities. These results aim to provide a theoretical basis for channel management and pricing strategies in the reverse supply chain and further enrich the managerial insights.

1. Introduction

Waste Electrical and Electronic Equipment (WEEE) are discarded devices and appliances that use electricity, such as computers, mobile phones, and refrigerators [1]. With the acceleration of the replacement of electronic products, the amount of WEEE has shown rapid growth in general. In 2016, the global amount of electronic waste (e-waste) was approximately 44.7 million metric tons (Mt) and is expected to grow to 52.2 million Mt in 2021. The annual growth rate has reached 3% to 4%, but less than 20% can be effectively recovered [2]. Randomly discarded e-waste will cause serious environmental pollution (on air, dust, soil, sediments, plants, and so on), which poses a threat to human health [3, 4]. The recycling of e-waste is essential to the sustainable development of the electronics industry as a secondary source of critical metals, and it will contain greater recycling value with improvement in science and technology [5–7]. Under the dual effects of resource sustainability and environmental hazards, the recycling and reuse of WEEE should be taken into account.

However, as the top e-waste producer in the world, less than 20% of the WEEE generated in China has been documented to be recycled in recent years [2]. According to a survey conducted in Zhuhai, more than 50% of the residents tended to store wasted mobile phones at home rather than recycling; price and convenience were found to be the primary factors that affected residents' willingness to participate in recycling [8]. The "Internet + recycling" model has the advantages of eliminating information asymmetry, reducing transaction costs, and expanding the scope and scale of recycling; it is more convenient than traditional methods. To promote the innovation of recycling models and explore the "Internet + recycling" model, China has also issued a series of policy guidelines, such as the 2015 Circular

Economy Promotion Plan, which accelerates the process of Internet + recycling in China [9].

With the development of big data and Internet technology, e-platforms have arisen in a new stage of rapid development and provide new ideas for WEEE recycling [10]. With the opening of the e-platform to third-party merchants, many recyclers have begun to enter the e-platform for recycling. For example, a specialized recycling business sector, Paipai, is opened on JD Mall (https://www.jd.com/), served by Aihuishou, Yifeng.com, and so on. In uSell (https://www.usell.com/), sellers can publish second-hand electronic products on the website, and qualified buyer agencies will bid on the e-platform. This is a way of ordering online and recycling offline. Firstly, users place their orders online and describe the condition of the electronic product on the e-platform. Then the recycler gives the price evaluation based on the description. After consumers accept the price and submit used products, they will be paid by the recycler in the form of third-party payment, and the e-platform earns the commission from each order for providing trading service, as shown in Figure 1.

In addition to recycling through the e-platform, recyclers can also open a direct online recycling channel, which has certain requirements for technology and capital. A self-built recycling channel is direct to customers without paying other third-party fees. For example, as China's largest recycler of second-hand 3C electronic products, Aihuishou not only has direct recycling channels but also cooperates with JD Mall and Huawei Mall to boost its recycling business. However, the addition of a direct recycling channel will inevitably lead to competition between channels. It is also an issue for the recycler to set recycling prices when there are multiple recycling channels. Generally speaking, recyclers usually pay consumers based on the residual value of used products. For example, Aihuishou will set the same recycling price on its official website and on the Paipai for products of the same quality. On the other hand, recyclers will also weigh the costs of different channels to set the price. For example, online recycling prices are usually higher than offline stores. Under the background of the coexistence of various recycling forms, the fundamental challenge faced by recyclers is how to manage recycling channels and formulate scientific price strategies, to achieve economic and environmental sustainability. Should recyclers build direct recycling channels? And if so, how should they set recycling prices for different channels? Answering these questions is critical to the development of the recycling industry.

In the dual-channel reverse supply chain, consumers' preference for recycling channels affects the decision-making of recyclers and the supply chain performance. When dual recycling channels exist, the e-platform can attract consumers by providing better recycling services, allowing consumers to inquire about past transactions before placing an order and making correct decisions [11, 12]. In the research, we introduce consumers' preferences for channels and construct three reverse supply chains to focus on the recycler's channel selection and pricing strategies using game theory. The following questions are attempted to be answered: (1) which recycling model is superior for enterprises and the supply chain? (2) How do consumers' preferences and channel competition affect the decision-making of the recycler and e-platform, as well as the supply chain performance? (3) Which recycling pricing strategy is better in the dual-channel reverse supply chain?

The primary contributions of this article are summarized as follows:

(i) In the context of e-platform recycling, we build a single-channel reverse supply chain model and two dual-channel reverse supply chain models and examine the impact of channel conflict on pricing strategy, extending previous research.

(ii) There are few studies on whether price discrimination in the reverse supply chain is effective. This article considers the pricing strategy of the recycler for different recycling channels to provide a basis for recyclers to formulate unified or differentiated prices strategy.

The rest of article is organized as follows. A related literature review is provided in Section 2. Section 3 gives the problem statement, assumptions, and notation, and three reverse supply chain models are constructed and solved using the Stackelberg game. Section 4 analyzes and compares equilibrium solutions and further discusses in terms of consumer surplus, environmental benefits, and corporate profits. Based on the results, managerial insights and practical implications are given in Section 5. Finally, conclusions and outlook are given.

2. Literature Review

In this section, we mainly focus on three streams of the related literature: reverse supply chain channel management, reverse supply chain pricing strategy, and consumer behavior.

2.1. Reverse Supply Chain Channel Management. Effective recycling channels for consumers to return WEEE are the key to improving recycling rates. So, some research has focused on the collection models under different situations. Savaskan et al. [13] and Ma et al. [14] studied closed-loop supply chain models with different single reverse channels. They showed that the retailer (agent) was the most effective undertaker of recycling. Chuang et al. [15] extended the research of Savaskan et al. [13] and found that the cost of recycling will affect the manufacturer's best recycling channel choice. Tirkolaee et al. [16] designed a sustainable mask closed-loop supply chain network during the COVID-19 pandemic and found that the costs of supply chain can be reduced by using recycling operations. Lotfi et al. [17] proposed medical waste chain network design that considers resiliency and sustainability. Gu et al. [18] explored that the manufacturer is more willing to recycle directly instead of entrusting others if processed by itself. And increasingly, studies have expanded from single recycling channels to dual recycling channel situation. Whether a dual recycling

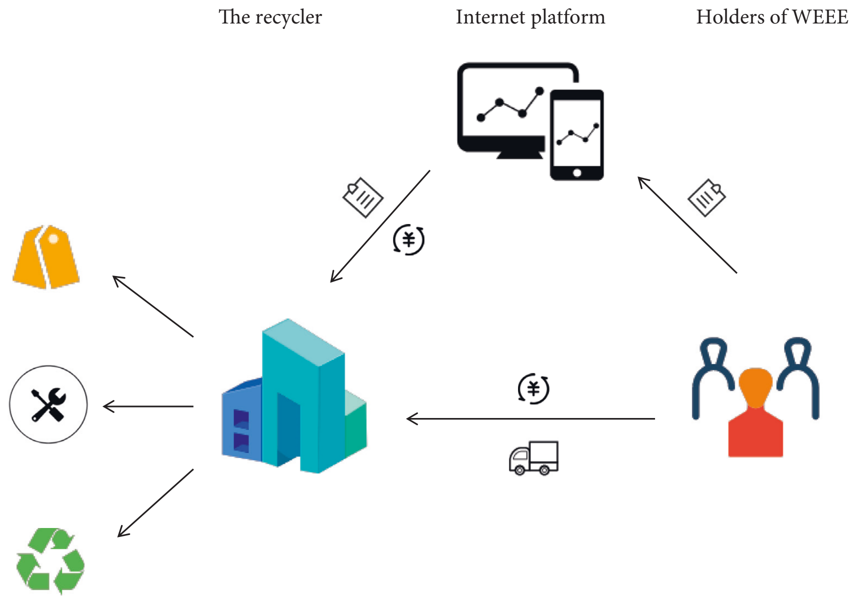


Figure 1: Reverse supply chain with E-platform channel.

channel outperforms a single-channel depends on the competitive intensity, dual-channel recycling is better than single-channel recycling only when the competition in dual channels is not very intense [19, 20]. Hong et al. [20] and Liu et al. [21] extended this and introduced hybrid dual-channel recycling modes (manufacturer and retailer dual recycling model, retailer and third-party dual recycling model, manufacturer and third-party dual recycling model, respectively) into the closed-loop supply chain. Under the same condition, the amounts that the manufacturer and retailer collected together was superior to that of the other two models and single-channel recycling model.

The studies above focus on traditional recycling modes; with the rise in "Internet + recycling," many studies have expanded from traditional recycling channels to online. Feng et al. [22] derive that the online recycling channel can serve as a lever to force the recycler to enhance the recycling price in traditional recycling channels and help the dealer and the supply chain improve profits. However, Li et al. [23] discovered that the introduction of an online channel can be beneficial or harmful and the mixed recycling channels model may be worse off than the single offline recycling channel model in terms of system profit. Chen et al. [24] developed a dual-channel reverse supply chain by introducing online recycling channels based on offline TPRs, uncovering that the benefits of recycling centers are affected by consumer sustainability awareness and the logistics costs of the online channel.

E-platform can use data collection and analysis to provide personalized and targeted promotional services through segment customers [25]; it also plays an increasingly important role in the reverse supply chain. Xiang and Xu [26] found that enterprises could obtain higher goodwill through cooperation with Internet service platforms. Ren et al. [27] explored a cooperative relationship between the manufacturer and Internet sharing platform that purchases new products from the manufacturer and leases products to customers in two structures, without and with recycling, and the results showed that the cooperative model was superior to the noncooperative model in terms of profitability and services for both parties. Wang et al. [28] developed a low-carbon e-commerce closed-loop supply chain (LCE-CLSC) consisting of the remanufacturer and the e-commerce platform and found that the altruistic preference behavior increases the revenue of the e-platform and improves the efficiency of the LCE-CLSC. Based on "Internet + recycling", Jian et al. [29] proposed collection effort cost-sharing mechanisms to optimize the collaborative recycling strategy between a third-party collector and an e-business platform, finding that it is more profitable for the collector and the e-business platform to share a portion of the other's collection investments under the cooperative mode. Zhang et al. [30] considered the technological innovation of a third-party Internet recycling platform and found that carbon reduction was better when the third party leads recycling.

2.2. Reverse Supply Chain Pricing Strategy.

The price strategy of the reverse supply chain is closely related to the recycling volume, corporate profit, and consumer welfare, and many scholars have conducted in-depth studies on it. Giri et al. [31] investigated the optimal pricing strategy for the dual-channel closed-loop supply chain when a different member of the supply chain is dominant (e.g., manufacturer, retailer, and third-party) and found that higher profit can be achieved when the retailer is dominant. Ranjbar et al. [32] reached a similar conclusion. In addition, some scholars have also studied the influence of product quality and consumers' bargaining power on dual-channel reverse supply chain pricing decisions [33–35].

With the emergence of Internet platforms in the reverse supply chain, several scholars have studied the pricing decisions under this recycling model [26, 28, 36, 37]. However, related studies have mainly focused on qualitative analysis or single-channel recycling and mostly have been conducted on (re)manufacturers and retailers. In fact, third-party recycling is a more common model and competition between recycling channels is widespread. In particular, regarding the pricing strategy of the dual-channel reverse supply chain, most studies focus on the form of separate pricing for different recycling channels, while in real life, some specialized and large-scale recycling enterprises adopt a uniform pricing model, and this pricing strategy also needs our attention.

2.3. Consumer Behavior. Consumer behavior can affect the choice of reverse supply chain and enterprises' decision-making. In the multichannel reverse supply chain, recyclers in different channels will adopt some strategies to attract consumers, such as recycling price, service level, and channel convenience [38]. Wang et al. [39] built an extended theory of planned behavior (TPB) theoretical framework to find that perceived behavior control, subjective norms, attitudes, and economic motivation had a significant positive impact on residents' willingness to participate in online recycling. With the development of the Internet + recycling, online recycling with more convenience and privacy attracts increasing concern. The recycling price has no longer the only factor that affects consumers' recycling decisions; this also affects the decision-making of recyclers. He et al. [40] found that the convenience of channel has an impact on recycling efficiency. Wang et al. [11] constructed a closed-loop supply chain composed of a manufacturer, a retailer, and a third-party platform.

Preference for third-party recycling platforms will affect the price decisions of retailers and third-party recycling platforms. Kang et al. [12] studied the dual-channel recycling problems based on different regions and found the changes in consumers' preference for the online channel have an effect on optimal decisions and profits of multiregion recycling companies. Feng et al. [22] established a two-stage reverse supply chain model composed of a recycler and a dealer, which involves a traditional channel and online channel. They find that consumers' preference for online recycling channels will affect dealer's choice of coordination mechanisms. Li and Feng [41] discovered that there exists a Pareto interval with respect to consumers' preference for the online channel, which makes the profits of WEEE disposers and collectors under the dual recycling channel higher than the corresponding profits under the single recycling channel. Unlike the above studies, we study the impact of consumers' preferences not for the online channel but for the e-platform channel on firms' pricing decisions, to further balance the profitability of the dual channels.

The above literature has primarily considered the traditional, self-built online recycling model or single-channel reverse supply chain with e-platform participation; few studies have considered competition in the context of e-platform recycling and unified pricing strategy. The more relevant article to our research is the study by Wang et al. [28]; however, they do not consider reverse channel competition and the resulting consumers' preference for channels. In this article, we build the single-channel reverse supply chain model and the dual-channel reverse supply chain models consisting of the recycler and the e-platform. In the dual-channel reverse supply chain, we investigate the impact of the recycler's pricing strategy (unified and differentiated) on supply chain performance. A brief summary of the literature review is shown in Table 1 to clarify the novelty of this research.

3. Problem Statement

3.1. Problem Statement. Three reverse supply chain models are developed in this study, as shown in Figure 2. (1) Single-channel recycling model (Model-S), the recycler only recycles WEEE through the e-platform channel. The recycler pays commissions to the e-platform for unit recycling WEEE and gains profits through further processing of WEEE. This pattern is becoming increasingly common with the development of the Internet platform. (2) For the dual-channel recycling model with unified prices (Model-DU), in this model, the recycler builds own recycling channel in addition to settling in the e-platform. The recycler sets the same recycling price for the same quality of used electronics for different channels. (3) For the dual-channel recycling model with differentiated prices (Model-DD), the only difference from Model-DU is that the recycler price of the two channels separately and the recycling prices of the self-built channel and the e-platform channel are p_r and p_p respectively. The related symbols used in this article are summarized in Table 2.

3.2. Assumptions. Assume that the recycling volume is a linear function with respect to recycling price: in Model-S, $q = S + ap_p$. When there are two recycling channels, the recycling volume of one channel is influenced not only by the recycling price of its own channel but also by the recycling price of another channel. In the Model-DD, the demand functions with respect to the recycling prices can be given by the following [42]:

$$\begin{aligned} q_p &= \theta S + a p_p - b\left(p_r - p_p\right), \\ q_r &= (1-\theta)S + a p_r - b\left(p_p - p_r\right), \end{aligned} \tag{1}$$

where θ denotes the consumers' preference for the e-platform channel and $1-\theta$ represents consumers' preference for the self-built channel, $0 < \theta < 1$. In Model-S, there is no consumer preference. b can be explained as the competition intensity between channels.

In the e-platform channel, the total expenditure of the recycler is the sum of recycling price and commission; that is $\omega = p^p + m$; the decision variable of the e-platform is commission (m). To simplify the calculation, use ω as the decision variable of the recycler. Then the demand function under the single-channel recycling model can be further expressed as follows:

$$q = S + a(\omega - m). \tag{2}$$

Table 1: Summarized literature review.

Reference	Structure of supply chain		Channel selection	Number of reverse channels		Members					Pricing strategy of two channels	
	Reverse supply chain	Closed-loop supply chain		1	2	Third-party recycler	Manufacturer	Retailer	E-platform	Recycling center	Unified	Differentiated
Savaskan et al. [13]		√	√	√		√	√	√				
Ma et al. [14]		√	√	√		√	√	√				
Huang et al. [19]		√			√	√	√	√				√
Giri et al. [31]		√			√	√	√	√				√
Liu et al. [33]	√				√	√						√
Feng et al. [22]	√		√	√	√	√						√
Li et al. [23]	√		√	√	√	√	√					√
Xiang and Xu [26]		√		√			√	√	√			
Ren et al. [27]		√		√			√		√			
Wang et al. [28]		√		√			√		√			
Jian et al. [29]	√				√	√		√	√			
Chen and Gao [36]		√	√	√		√	√		√			
Ma and Hu [37]		√		√			√	√	√			
Chen et al. [24]	√		√	√	√	√				√	√	√
This paper	√		√	√	√	√			√		√	√

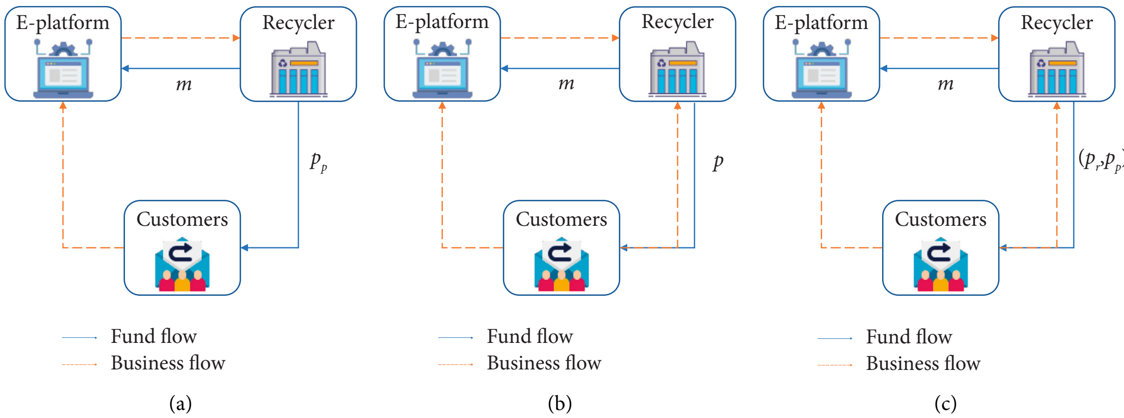


FIGURE 2: Schematic diagram of the reverse supply chain. (a) Single channel. (b) Dual channel with unified pricing. (c) Dual channel with differentiated pricing.

TABLE 2: Description of the symbols of this article.

Symbols	Description
Indices	
i	Index of recycling models, $i \in \{S, DU, DD\}$
j	Index of recycling channels, $j \in \{p, r\}$
Superscripts/subscripts	
S, DU, DD	Single-channel recycling model, dual-channel recycling model with unified pricing and dual-channel recycling model with differentiated pricing, respectively
p, r	E-platform channel and self-built channel, respectively
$i*$	Optimal values for model i
Parameters	
S	Basic recycling members when recycling price is zero
a	Elasticity coefficient of the recycling price
b	Elasticity coefficient of the cross recycling price
θ	The consumers' preference for platform channel
Δ	The recycler's unit profit by processing WEEE
Decision variables	
ω	Total payment of the recycler
m	Commission charged by the e-platform
p_r	Recycling price of the self-built channel
Derived functions	
q_j^i	Recycling volumes of channel j in model i
q^i	Total recycling volumes in model i
π_r^i	Profit of the recycler in model i
π_p^i	Profit of the e-platform in model i
π^i	The profit of the reverse supply chain in model i

The demand functions under the dual-channel recycling models can be expressed as follows:

$$\begin{aligned} q_p &= \theta S + a(\omega - m) - b(p_r - \omega + m), \\ q_r &= (1-\theta)S + a p_r - b(\omega - m - p_r). \end{aligned} \tag{3}$$

Assumption 1. The recycler and the e-platform play a Stackelberg game, and the recycler serves as the game leader. Both parties are rational completely; they make decisions to maximize their own profits.

Assumption 2. E-platform merchant entry fees usually include an annual fee, deposit, and commission, since the annual fee and deposit are one-time and have no effect on the results; therefore, they are set to 0e

Assumption 3. Assume that the basic recycling volume under the single-channel and dual-channel recycling models are equal, and the recycled wasted electronic products have homogeneity.

TABLE 3: The optimal decisions in Model-S, Model-DU, and Model-DD.

	Model-S	Model-DU	Model-DD
Recycling price of e-platform channel	$(a\Delta - 3S)/4a$	$(2a\Delta - (1+2\theta)S)/6a$	$((-a(3a+4b)\theta - 2(a+b)b)S + a(a+2b)^2\Delta)/4a(a+b)(a+2b)$
Recycling price of self-built channel	n/a	$(2a\Delta - (1+2\theta)S)/6a$	$((a\theta - a - b)S + a(a+2b)\Delta/2a(a+2b)$
E-platform's commission	$(S + a\Delta)/4a$	$(2a\Delta + (4\theta - 1)S)/6a$	$(\theta S + a\Delta)/4(a+b)$
Recycling quantity of WEEE	$(S + a\Delta)/4$	$(2a\Delta + 2(1-\theta)S)/3$	$(-a\theta + 2(a+b)]S + a(3a+4b)\Delta)/4(a+b)$
E-platform's profit	$(S + a\Delta)^2/16a$	$(2a\Delta + (4\theta - 1)S)]^2)/36a$	$(\theta S + a\Delta)^2/16(a+b)$
Recycler's profit	$(S + a\Delta)^2/8a$	$(4a^2\Delta^2 - 8a(\theta-1)S\Delta - (8\theta^2 - 4\theta - 1)S^2/12a$	$(a(a+2b)(a(3a+4b)\Delta^2 + (4(a+b) - 2a\theta]\Delta S)$ $+ (a((3a+2b)\theta^2 - 4(a+b)\theta) + 2(a+b)^2)S^2)/8a(a+b)(a+2b)$
Profit of the reverse supply chain	$3(S + a\Delta)^2/16a$	$[a\Delta + (1-\theta)S][4a\Delta + (1+2\theta)S]/9a$	$(a(a+2b)(a(7a+8b)\Delta^2 + (8(a+b) - 2a\theta]\Delta S)$ $+ (a((7a+6b)\theta^2 - 8(a+b)\theta) + 4(a+b)^2)S^2/16a(a+b)(a+2b)$

Assumption 4. In addition to the recycling price and platform commission, other recycling costs (such as logistics cost and testing cost) are not considered.

3.3. Models and Solution. In this section, three reverse supply chain models are constructed and solved; optimal recycling prices, optimal recycling volumes, and optimal profits are calculated.

3.3.1. Model-S. In the Model-S, customers can participate in recycling only through the e-platform. The profit functions of the recycler and the e-platform are formulated as follows:

$$\pi_r^S(\omega) = (\Delta - \omega)[S + a(\omega - m)],$$
$$\pi_p^S(m) = m[S + a(\omega - m)]. \quad (4)$$

The recycler, as the leader, decides ω first; the e-platform then decides the commission m. Note that $d^2\pi_p^S(m)/dm^2 = -2a < 0$, $\pi_p^S(m)$ is a concave function of m. Therefore, we can derive the e-platform's best response is as follows:

$$m = \frac{S + a\omega}{2a}. \quad (5)$$

By substituting equations (5) into (6), it is easy to find that $\pi_r^S(\omega)$ is a concave function of ω. According to the first-order condition of $\pi_r^S(\omega)$ with respect to ω, we derive that

$$\omega^{S*} = \frac{a\Delta - S}{2a}. \quad (6)$$

After substituting equations (6) into (5), the e-platform's optimal decision and optimal recycling price can be calculated as follows:

$$m^{S*} = \frac{S + a\Delta}{4a},$$
$$p_p^{S*} = \omega^{S*} - m^{S*} = \frac{a\Delta - 3S}{4a}. \quad (7)$$

3.3.2. Model-DU. In the Model-DU, the e-platform channel and self-built channel exist simultaneously; the recycling prices of the two channels are equal and expressed as follows: $p = p_r = p_p = \omega - m$. Profit functions of the recycler and the e-platform are as follows:

$$\pi_r(\omega) = (\Delta - \omega)[\theta S + a(\omega - m)] + [\Delta - (\omega - m)][(1-\theta)S + a(\omega - m)],$$
$$\pi_p(m) = m[\theta S + a(\omega - m)]. \quad (8)$$

The optimal decisions of the recycler and the e-platform can be obtained in Table 3 by backward induction.

3.3.3. Model-DD. In the Model-DD, consumers can also participate in recycling through the e-platform channel or self-built channel. Different from Model-DU, the recycler can develop different recycling prices for different channels. The profit functions of the recycler and the e-platform are given by

$$\pi_r(\omega, p_r) = (\Delta - \omega)[\theta S + a(\omega - m) - b(p_r - \omega + m)] + (\Delta - p_r)[(1-\theta)S + ap_r - b(\omega - m - p_r)],$$
$$\pi_p(m) = m[\theta S + a(\omega - m) - b(p_r - \omega + m)]. \quad (9)$$

At first, the recycler determines ω and the recycling price of the self-built channel p_r. Then, the e-platform determines commission m based on the decisions of the recycler.

Note that $d^2\pi_p/dm^2 = -2(a+b) < 0$, where $\pi_p(m)$ is a concave function of m. Therefore, we can derive the e-platform's best response is

$$m = \frac{\theta S + (a+b)\omega - bp_r}{2(a+b)}. \quad (10)$$

By substituting the equations (10) into (14), we get the Hessian matrix of $\pi_r(\omega, p_r)$ as

$$H(\omega, p_r) = \begin{bmatrix} \frac{\partial^2\pi_r}{\partial\omega^2} & \frac{\partial^2\pi_r}{\partial\omega\,\partial p_r} \\ \frac{\partial^2\pi_r}{\partial p_r\partial\omega} & \frac{\partial^2\pi_r}{\partial p_r^2} \end{bmatrix} = \begin{bmatrix} -(a+b) & b \\ b & \frac{-(2a^2 + 4ab + b^2)}{a+b} \end{bmatrix}. \quad (11)$$

Since $\partial^2\pi_r/\partial\omega^2 < 0, \partial^2\pi_r/\partial p_r^2 < 0, |H(\omega, p_r)| = 2a(a+2b) > 0$, $\pi_r(\omega, p_r)$ is a joint concave function of ω and p_r. The optimal decisions of the recycler can be obtained from the first-order condition as

$$\omega^{DD*} = \frac{-(a\theta + b)S + a(a+2b)\Delta}{2a(a+2b)}, \quad (12)$$

$$p_r^{DD*} = \frac{(a\theta - a - b)S + a(a+2b)\Delta}{2a(a+2b)}. \quad (13)$$

The optimal commission can be obtained by substituting the equations (12) and (13) into (10):

$$m^{DD*} = \frac{\theta S + a\Delta}{4(a+b)},$$
$$p_p^{DD*} = \omega^{D*} - m^{D*} = \frac{[-a(3a+4b)\theta - 2(a+b)b]S + a(a+2b)^2\Delta}{4a(a+b)(a+2b)}. \quad (14)$$

Substituting the optimal decisions under the three models into the demand functions and profit functions, the optimal recycling quantities and profits of the supply chain can be further obtained; all optimal solutions are shown in Table 3.

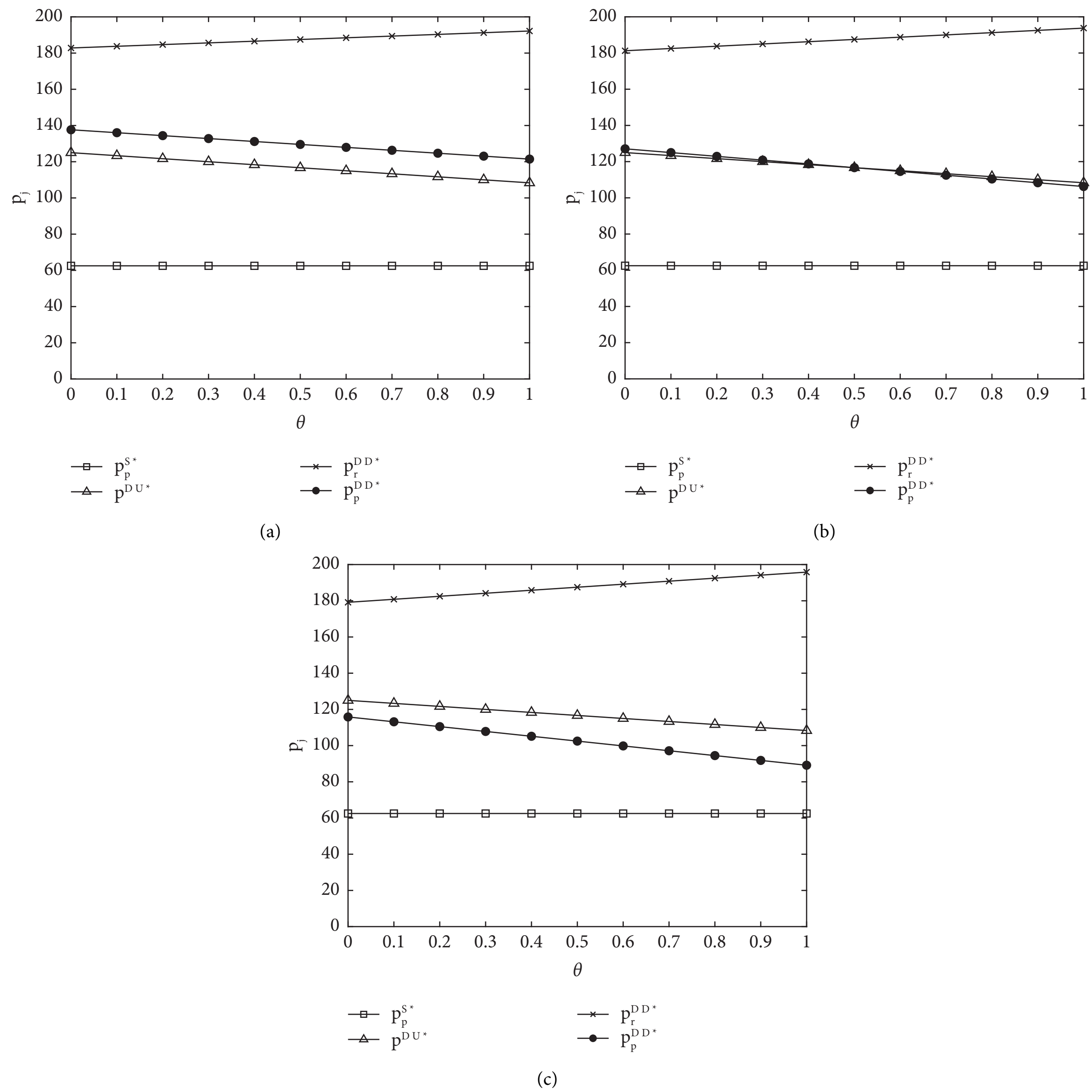


Figure 3: Comparison of optimal recycling prices among three models: (a) $b = 0.5$; (b) $b = 0.3$; (c) $b = 0.15$.

4. Results

4.1. Sensitivity Analysis

Proposition 1. *In the Model-S, Model-DU, and Model-DD, $m^{i*}, p_j^{i*}, q^{i*}, \pi_j^{i*}, \pi^{i*}$ are increasing and convex functions with respect to Δ.*

Proposition 1 can be obtained by the first and second derivatives of the equilibrium solutions under three models with respect to Δ. Proposition 1 shows that the high disposal revenue of WEEE makes the recycler increase the recycling price to attract consumers to participate in recycling. With the same minimum price accepted by consumers, consumer surplus increases and more WEEE can be recycled, resulting in higher profits for the recycler and the e-platform. In other words, high processing revenue is beneficial to the enterprises, consumers, and environment, and this positive effect is marginally increasing. Therefore, recyclers should make efforts in promoting recycling technologies, optimizing recycling process for a higher benefit.

Proposition 2. *In the Model-DU and Model-DD, $m^{i*}, p_r^{DD\,*}$ are increasing functions with respect to θ and $p_r^{DU\,*}, p_p^{i*}, q^{i*}$ are decreasing functions with respect to θ.*

Proposition 2 can be obtained by the first derivative of the optimal results with respect to θ in the Model-DU and Model-DD. It is obvious that when consumers show a higher preference for e-platform recycling channels, the e-platform will charge higher commission. In order to reduce the recycling cost, the recycler will uniformly reduce the recycling price of both channels in the Model-DU. And in the Model-DD, the recycler will increase the recycling price of the self-built channel while reducing the recycling price of the platform channel. In short, as consumers' preference for e-platform channels increases, the recycler will face higher recycling costs. This leads to a reduction in recycling volume and poses a threat to recycling efficiency and environmental sustainability.

Proposition 3

(1) *In the Model-DU and Model-DD, π_p^{i*} is an increasing and convex function with respect to θ, π_r^{DU*}, π^{DU*} are decreasing and concave functions with respect to θ, and π_r^{DD*} is a decreasing and convex function with respect to θ.*

(2) *If $\Delta < (3a + 2b)S/a(a + 2b)$ and $\theta > \theta^*$ are satisfied, π^{DD*} is an increasing function with respect to θ; otherwise, π^{DD*} is a decreasing function with respect to θ. $\theta^* = (a(a + 2b)\Delta + 4(a + b)S)/(7a + 6b)S$.*

Proof of Proposition 3. See Appendix

Proposition 3 shows that consumers' preference for the e-platform channel is beneficial to the e-platform but harmful to the recycler because the recycler needs to pay higher commissions. With the increase in consumers' preference for e-platform, this positive effect is more pronounced for the e-platform. But for the recycler, there are different scenarios: in the Model-DU, the recycler's profit decreases faster as θ increases; on the other hand, in the Model-DD, the recycler can use a differentiated pricing strategy to reduce losses. This also reflects the flexibility and environmental adaptability of Model-DD.

In addition, the supply chain profit in the Model-DU is negatively correlated with θ. While in the Model-DD, when the disposal revenue of WEEE is low and consumers' preference for e-platform channel is beyond the threshold θ^*, the supply chain profit is positively related to θ, vice versa. In short, in the dual-channel reverse supply chain, recyclers should build an effective self-built channel to attract consumers by improving service quality and optimizing recycling process instead of relying solely on e-platforms.

Proposition 4. (1) *m^{DD*} is a decreasing function with respect to b.*

(2) *If $\theta < 1/2$, p_r^{DD*} is an increasing function with respect to b; otherwise, p_r^{DD*} is a decreasing function with respect to b. If $\{\Delta < 2(a + b)^2 S/a(a + 2b)^2\} \cap \{\theta < \overline{\theta}\}$ are satisfied, p_p^{DD*} is a decreasing function with respect to b; otherwise, p_p^{DD*} is an increasing function with respect to b. $\overline{\theta} = (2(a + b)^2 S - a(a + 2b)^2\Delta)/(5a^2 + 12ab + 8b^2)S < 1/2$.*

(3) *q_p^{DD*} is independent of b, and q_r^{DD*}, q^{DD*} are increasing functions with respect to b.*

Proof of Proposition 4. See Appendix .

Proposition 4 demonstrates how the recycler and the e-platform respond to changes in competition intensity between channels. Firstly, as the competitive intensity between channels increases, the commission charged by the e-platform always decreases. Secondly, recycling prices in different channels are related to consumers' preference for channels and the disposal revenue of WEEE. When consumers prefer the self-built channel, as competition intensity between channels increases, the recycler will increase the recycling price of a self-built channel to attract consumers and will also increase the recycling price of the e-platform channel when the recycler is profitable. On the contrary, when consumers prefer the e-platform channel, the recycler will reduce the recycling price of their own channel and increase the recycling price of the e-platform channel, relying on the platform's customer resources to recycle more WEEE. In addition, $\overline{\theta}$ is negatively correlated with b; in other words, when the channel competition is fierce, the recycler is more likely to increase recycling prices of both channels even if consumers' preference for the e-platform channel is low because this can diminish the price difference and weaken channel conflict.

Therefore, in the dual-channel reverse supply chain, the recycler needs to comprehensively consider the consumers' preferences and profit of the recycling industry to formulate the optimal pricing strategy in a different competitive environment. In addition, channel competition also positively impacts the recycling quantities of the reverse supply chain. To realize a circular economy, the government should encourage recyclers to build their own recycling channels and guide orderly competition in the recycling market.

Proposition 5. *When $\{\sqrt{10}/10a < b < \sqrt{3}/3a\} \cap \{\theta < \theta_0\}$ or $b > \sqrt{3}/3a$ is satisfied, $p_p^{S*} < p^{DU*} < p_p^{DD*} < p_r^{DD*}$; otherwise, $p_p^{S*} < p_p^{DD*} < p^{DU*} < p_r^{DD*}$. $\theta_0 = (2(a^2 - b^2)S + a(4b^2 - a^2)\Delta/(5a^2 - 8b^2)S$.*

Proof of Proposition 5. See Appendix .

Proposition 5 indicates that the recycling price of the dual-channel recycling model are higher than that of the single-channel recycling model. Thus, the competition between channels is conducive to improving consumer surplus. In the Model-DD, the recycler will provide the highest recycling price among the three models. When the competition intensity between channels is relatively low ($b < \sqrt{10}/10a$), p^{DU} is higher than p_p^{DD*}, because when the channel competition is not too fierce, the recycler has no greater willingness to raise prices, and a unified pricing strategy forms certain constraints and avoids negative pricing by the recycler. When the competition intensity between channels is relatively high ($b > \sqrt{3}/3a$), p_p^{DD*} is higher than p^{DU}, because a differentiated pricing strategy can flexibly adapt to changes in the competitive environment. When the competition intensity between channels is moderate ($\sqrt{10}/10a < b < \sqrt{3}/3a$), if consumers have a low preference for the e-platform channel, p_p^{DD*} is higher than p^{DU}; otherwise, p^{DU} is higher.

It can be seen from $\partial\theta_0/\partial b = 12a^2 b(2a\Delta + S)/(5a^2 - 8b^2)^2 S > 0$ that the threshold, θ_0, increases as b increases, showing that the price advantage in the Model-DU continues to weaken as the competition intensity between channels increases. As shown in Figure 3 ($S = 30$, $a = 0.6$, $\Delta = 400$), $p_p^{DD\,*}$ decreases faster than $p^{DU\,*}$. When competition intensity between channels is moderate, there exists a point of intersection with respect to the consumers' preference for channels, which means the price advantage of $p_p^{DD\,*}$ gradually decreases with θ increases.

Proposition 6

(1) $\pi_r^{S\,*} < \pi_r^{DU\,*} < \pi_r^{DD\,*}$

(2) If $\{\Delta < 5S/a\} \cap \{\theta < \theta_1\}$ *is satisfied,* $\pi_p^{DD\,*} < \pi_p^{DU\,*} < \pi_p^{S\,*}$*; otherwise,* $\pi_p^{DD\,*} < \pi_p^{S\,*} < \pi_p^{DU\,*}$. $\theta_1 = (5S - a\Delta)/8S$.

(3) $\pi^{S*} < \pi^{DU\,*}$, $\pi^{S*} < \pi^{DD\,*}$.

Proof of Proposition 6. See Appendix .

Proposition 6 (1) shows that the recycler's profit in the Model-DD is the highest among three model, in other words, it is beneficial for the recycler to build its own channel. At the same time, a differentiated pricing strategy can provide the recycler with a larger pricing space, to obtain higher profit, as shown in Figure 4 (the parameter values are $S = 30, a = 0.6,\ b = 0.3, \Delta = 400$). Moreover, the recycler's optimal profit under Model-DU is more susceptible to changes in consumers' preferences than Model-DD. This illustrates that Model-DD enables the recycler to adjust its own decisions in accordance with external changes to avoid greater profit losses.

For the e-platform, the Model-DD is always unfavorable because the e-platform is at a disadvantage in channel competition. When the disposal revenue of WEEE and consumers' preference for e-platform is low, Model-S is better for the e-platform; otherwise, Model-DU is preferable, as shown in Figure 5 ($S = 30, a = 0.6, b = 0.3$). That is because high consumers' preference for e-platform channels or high profitability of the recycler helps the e-platform to obtain higher commission and profit, even if there exists another recycling channel. Therefore, the e-platform should strive to improve its reputation and cultivate more platform users.

Regarding Proposition 6 (3), compared to Model-S, the dual-channel recycling model can bring more profit to the supply chain. Figure 6 ($S = 30, a = 0.6, \Delta = 400$) shows the comprehensive impact of consumers' preferences and competitive intensity on the supply chain's profit. The profit of the reverse supply chain in the Model-S is independent of b, θ. It can be seen that π^{DU*} is higher than π^{DD*} only when competition intensity between channels is low and consumers' preference for the e-platform is not too high. Although the recycler building its own recycling channel will cause losses of the e-platform, under certain conditions, both parties can achieve a win-win situation through profit sharing in the Model-DD.

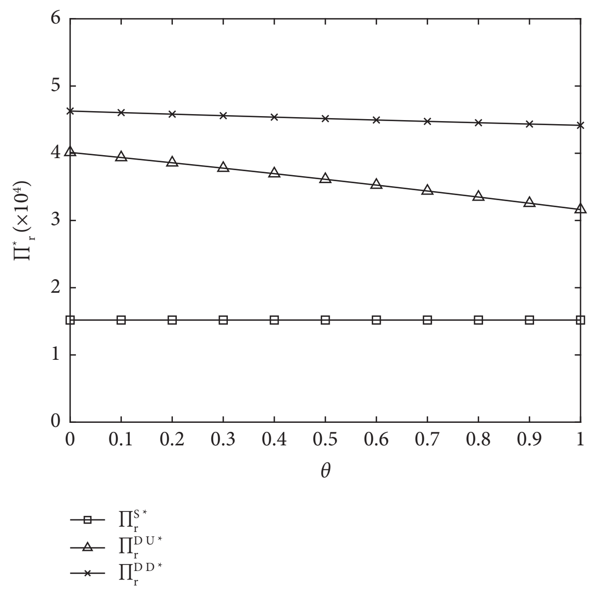


Figure 4: Comparison of optimal recycler's profits among three models.

Proposition 7. $q^{S*} < q^{DU*} < q^{DD*}$.

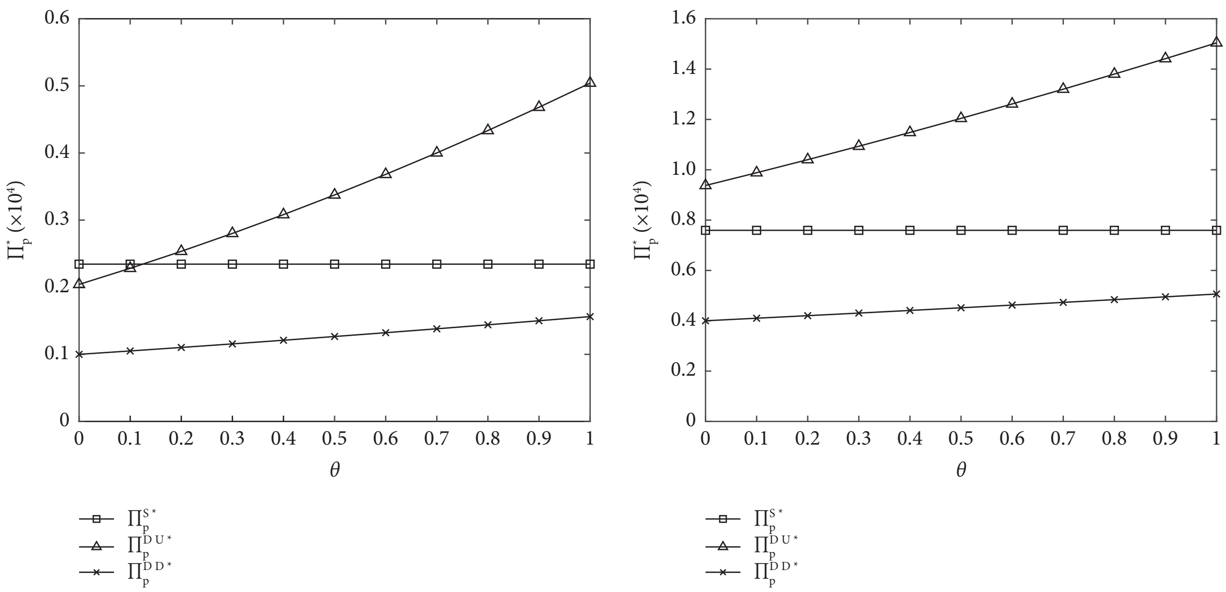
Proof of Proposition 7. See Appendix.

Proposition 7 indicates that the recycling quantities in the Model-DD are the highest among the three models, while in the Model-S, they are the lowest. Compared to Model-DU, Model-DD takes advantage of pricing flexibility to improve the recycling efficiency of the reverse supply chain and is superior in terms of resource reuse. Therefore, to promote the circular economy and environmental sustainability, the government should encourage recyclers to establish their own recycling channels and further improve the recycling efficiency of WEEE through competition between channels.

Setting $S = 30, a = 0.6, \Delta = 400$, the effect of consumers' preference for channels on recycling quantities in the three models is shown in Figure 7(a). It is consistent with Proposition 2 that the recycling quantities in the Model-DU and Model-DD decrease with θ; it also can be seen that recycling quantities in the Model-DU are more sensitive to θ than in Model-DD. Therefore, Model-DD is more stable in terms of recycling volume.

As shown in Figure 7(b), the recycling quantities in the Model-S and Model-DU are not affected by b. It is noted that the curve of q^{DD*} with respect to b is concave and increasing, which indicates that more e-wastes can be recycled with competition intensity increases, and the marginal increase is diminishing.

4.2. Discussion. In this section, we discuss the corporate profits, consumer surplus, and environmental benefits of different models based on a comparison of optimal results. Due to channel competition, the recycling price in the dual-channel reverse supply chain is always higher than that in the



(a) (b)

Figure 5: Comparison of optimal e-platform's profits among three models: (a) $\Delta = 200$; (b) $\Delta = 400$.

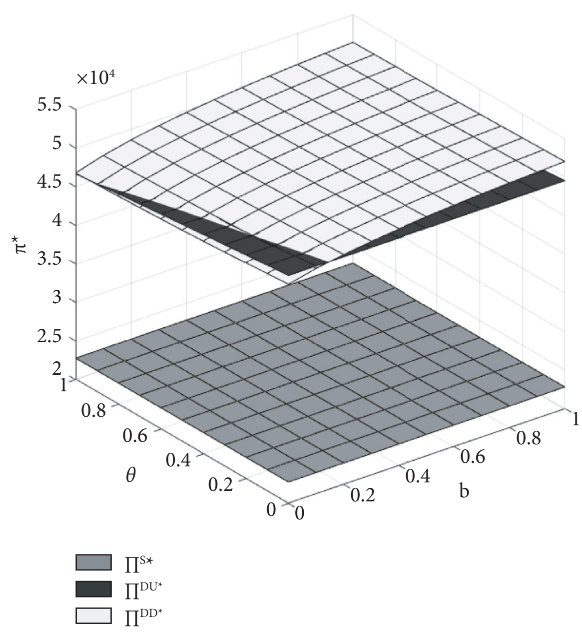


Figure 6: Comparison of optimal supply chain's profits among three models.

single-channel reverse supply chain, and the recycling price of the recycler's own channel in Model-DD is the highest among the three models. That is, competition between channels can increase consumer surplus. In addition, the recycling price of the e-platform channel with a differentiated pricing strategy is more sensitive to the consumers' preference, while the unified pricing strategy creates a certain constraint. In addition, the amount of WEEE recycling in Model-DD is higher than that in the other two models, achieving higher environmental benefits. As the intensity of channel competition increases, the system recycling volume increases. In terms of corporate profits, we find that the recycler has the highest profits in Model-DD while the e-platform prefers Model-DU or Model-S, which also reflects the positional advantage of the recycler in the game. By comparing supply chain profits under different models, we find that dual-channel reverse supply chains have higher total profits, and in some cases, the recycler and the e-platform may achieve a win-win situation by cooperation.

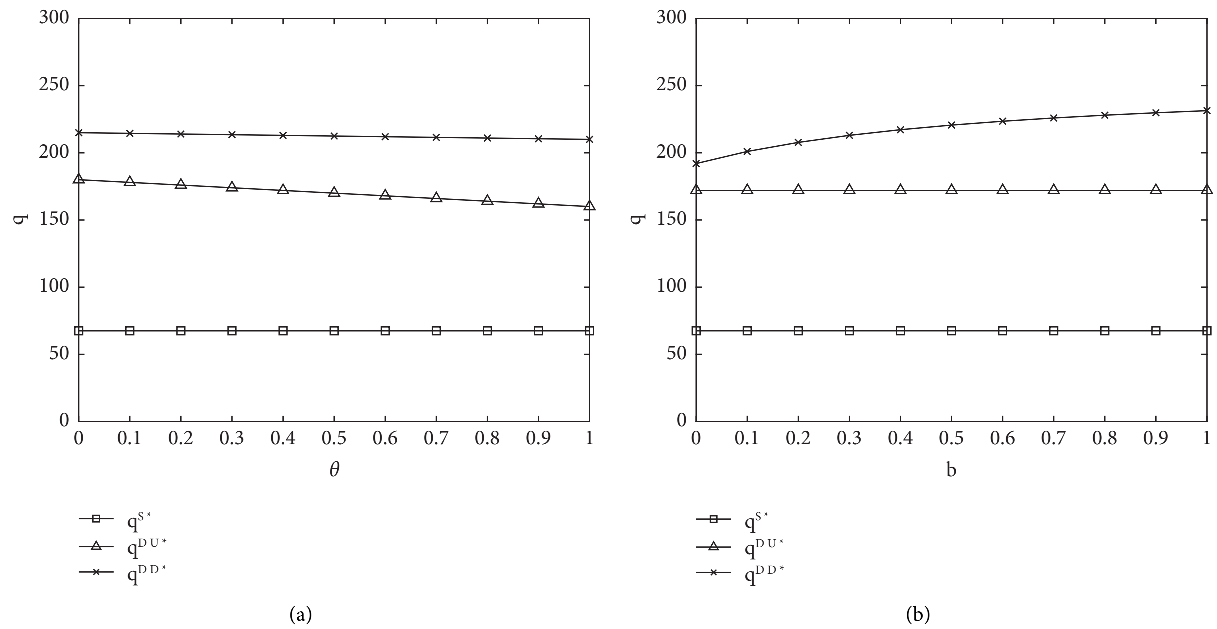


Figure 7: Comparison of optimal recycling volumes among three models: (a) $b = 0.3$; (b) $\theta = 0.4$.

5. Managerial Insights and Practical Implications

We construct three reverse supply chain models considering consumers' preference for channels, analyze and compare supply chain members' optimal decisions and profits, and further illustrate results using numerical examples. Some managerial insights are obtained as follows.

First, in terms of channel management, recyclers build their own recycling channels to facilitate the recovery of more e-wastes, and the competition between channels brings higher consumer surplus. Therefore, recycling enterprises should be encouraged to open direct recycling channels and explore diversified recycling systems to promote sustainable economic and environmental development. Second, e-platforms with high consumer preference will set higher commissions, and this will undoubtedly affect the interests of other stakeholders. Therefore, for some third-party network platforms in the reverse supply chain, it is necessary to restrict and guide the platform operators to set reasonable payment and settlement, platform commission, and other service fees to reduce the transaction fees of recyclers, promoting the efficient operation of the reverse supply chain. Finally, in the dual-channel reverse supply chains, the pricing strategy of recyclers should be formulated with careful consideration of the competitive environment and their own profitability. It is worth noting that the differentiated pricing strategy can be more flexible to adapt to changes in the external environment and reduce the profit loss of recyclers. However, when the competition intensity between channels is low, the unified pricing strategy can achieve higher supply chain profit.

6. Conclusions and Outlook

Based on the "Internet + recycling", we construct three reverse supply chain models consisting of the recycler and the e-platform and analyze the influence of consumers' preference for channels and channel competition on the supply chain equilibrium solution. We also compared optimal recycling prices, optimal profits, and optimal recycling quantities in the three models to explore the optimal recycling model from different angles. The main findings are listed as follows:

(i) It is proved that the high disposal revenue of WEEE is always beneficial to enterprises, consumers, and the environment. Therefore, the government should encourage enterprises to innovate processing technologies and improve resource utilization to build an efficient recycling system. It is also necessary to consider compatibility and cascade utilization in the product design stage, achieving higher reusable value.

(ii) Competition between channels can encourage enterprises to increase recycling prices and improve the recycling rate of WEEE. At the same time, a differentiated pricing strategy allows the recycler to flexibly adjust decisions to maximize own profits and environmental benefit. The government should promote the construction of a diversified recycling system and guide recycling enterprises to compete in an orderly manner.

(iii) In Model-DU and Model-DD, the high consumers' preference for e-platform channels is beneficial to the platform but harmful to the recycler. In Model-

DU, the consumers' preference for e-platform has a negative effect on the supply chain's profit. However, in Model-DD, if the disposal revenue of WEEE is low and consumers' preference for e-platform is beyond the certain threshold, the consumers' preference for e-platform has a positive effect on the supply chain's profit.

(iv) The recycler prefers Model-DD, while the e-platform prefers Model-S or Model-DU. When consumers' preference for channels and channel competition meet certain conditions, Model-DD has a higher total benefit than Model-DU, and a win-win situation may be achieved via in-depth cooperation, such as profit segmentation.

This study focuses on three recycling models based on e-platform considering consumers' preferences and provides some suggestions on pricing strategy and channel management for the recycler. In the future, the research can be expanded to multiple recyclers, the privacy protection during recycling can also be considered.

Appendix

Proof of Proposition 3. In the Model-DU, from the first and second derivative of the optimal profits with respect to θ, based on the nonnegative condition of optimal recycling price, $2a\Delta > (1+2\theta)S$, the authors can obtain

$$\frac{\partial \pi_p^{DU\,*}}{\partial \theta} = \frac{(8\theta-2)S^2 + 4a\Delta S}{9a} > \frac{4\theta S^2}{3a} > 0, \frac{\partial^2 \pi_p^{DU\,*}}{\partial \theta^2} = \frac{4S^2}{3a} > 0, \tag{A.1}$$

$$\frac{\partial \pi_r^{DU\,*}}{\partial \theta} = \frac{(4-16\theta)S^2 - 8a\Delta S}{12a} < -\frac{2\theta S^2}{a} < 0, \frac{\partial^2 \pi_r^{DU\,*}}{\partial \theta^2} = -\frac{2S^2}{a} < 0, \tag{A.2}$$

$$\frac{\partial \pi^{DU\,*}}{\partial \theta} = \frac{(1-4\theta)S^2 - 2a\Delta S}{9a} < -\frac{2\theta S^2}{3a} < 0, \frac{\partial \pi^{2DU\,*}}{\partial \theta^2} = -\frac{2S^2}{3a} < 0. \tag{A.3}$$

In the Model-DD, from the first and second derivative of the optimal profits with respect to θ, based on the nonnegative condition of $\omega^{DD\,*}$, $a(a+2b)\Delta > (a\theta + b)S$, the authors can obtain

$$\frac{\partial \pi_p^{DD\,*}}{\partial \theta} \tag{A.4}$$

$$\frac{\partial \pi_r^{DD\,*}}{\partial \theta} = \frac{-aS[(2a+2b-3a\theta-2b\theta)S + a(a+2b)\Delta]}{8a(a+b)(a+2b)} < 0$$
$$\frac{\partial^2 \pi_r^{DD\,*}}{\partial \theta^2} = \frac{aS^2(3a+2b)}{8a(a+b)(a+2b)} > 0, \tag{A.5}$$

$$\frac{\partial \pi^{DD\,*}}{\partial \theta} = \frac{-aS[(4a+4b-7a\theta-6b\theta)S + a(a+2b)\Delta]}{16a(a+b)(a+2b)}. \tag{A.6}$$

Set $\theta^* = a(a+2b)\Delta + 4(a+b)S/(7a+6b)S$, when $\theta < \theta^*, \partial\pi^{DD\,*}/\partial\theta < 0$; otherwise, $\partial\pi^{DD\,*}/\partial\theta > 0$.

To ensure the existence of θ^* in the interval range of (0,1), $\Delta < 3a + 2b/a(a+2b)S$ should be satisfied. If $\Delta > 3a + 2b/a(a+2b)S$, $\theta^* > 1$ holds constantly, at this time $\partial\pi^{DD\,*}/\partial\theta < 0$.

In summary, Proposition 3 can be proved. ☐

Proof of Proposition 4. In the Model-DD, after taking first-order derivatives of the recycler and the e-platform's optimal decisions with respect to b, the authors have

$$\frac{\partial m^{DD\,*}}{\partial b} = \frac{-a\Delta - \theta S}{4(a+b)^2} < 0, \tag{A.7}$$

$$\frac{\partial p_r^{DD\,*}}{\partial b} = \frac{(1-2\theta)S}{2(a+2b)^2}. \tag{A.8}$$

If $\theta > 1/2$, $\partial p_r^{DD\,*}/\partial b < 0$; otherwise, $\partial p_r^{DD\,*}/\partial b > 0$.

$$\frac{\partial p_p^{DD\,*}}{\partial b} = \frac{\left[\left(5a^2 + 12ab + 8b^2\right)\theta - 2(a+b)^2\right]S + a(a+2b)^2\Delta}{4(a+b)^2(a+2b)^2}. \tag{A.9}$$

Set $\overline{\theta} = 2(a+b)^2 S - a(a+2b)^2\Delta/(5a^2+12ab+8b^2)S$, based on the nonnegative condition of $p_p^{DD\,*}: a(a+2b)^2\Delta \geq [a(3a+4b)\theta + 2(a+b)b]S$, the authors have $\overline{\theta} < 1/2$.

Then if $\left\{\Delta < 2(a+b)^2/a(a+2b)^2 S\right\} \cap \left\{\theta < \overline{\theta}\right\}$ are satisfied, $\partial p_p^{DD\,*}/\partial b < 0$; otherwise, $\partial p_p^{DD\,*}/\partial b > 0$.

If $\Delta > 2(a+b)^2/a(a+2b)^2 S$, $\overline{\theta} < 0$ holds constantly; therefore, $\partial p_p^{DD\,*}/\partial b > 0$.

After taking first-order derivative of $q_r^{DD\,*}$ with respect to b, the authors have

$$\frac{\partial q_r^{DD\,*}}{\partial b} = \frac{a(a\Delta + \theta S)}{4(a+b)^2} > 0. \tag{A.10}$$

In summary, Proposition 4 can be proved. □

Proof of Proposition 5. To compare the optimal recycling prices in the three models, the authors compute the difference between recycling prices as follows:

$$p_p^{S*} - p_j^{DU*} = \frac{-a\Delta + (4\theta - 7)S}{12a} < 0, p_p^{S*} < p_j^{DU*}. \quad (A.11)$$

Based on the nonnegative condition of p_p^{S*}, $a\Delta \geq 3S$, the authors derive the following:

$$p_j^{DU\ *} - p_r^{DD\ *} = \frac{-a(a+2b)\Delta + [(-4b-5a)\theta + 2a + b]S}{6a(a+2b)} < 0, p_j^{DU\ *} < p_r^{DD\ *}, \quad (A.12)$$

$$p_p^{S*} - p_p^{DD\ *} = \frac{[a(3a+4b)\theta - (a+b)(3a+4b)]S - ba(a+2b)\Delta}{4a(a+b)(a+2b)} < 0, p_p^{S*} < p_p^{DD\ *}, \quad (A.13)$$

$$p_p^{DD\ *} - p_r^{DD\ *} = \frac{[-(5a+6b)\theta + 2(a+b)]S - a(a+2b)\Delta}{4(a+b)(a+2b)} < 0, p_p^{DD\ *} < p_r^{DD\ *}, \quad (A.14)$$

$$p_p^{DD\ *} - p^{DU\ *} = \frac{\left[\left(-5a^2 + 8b^2\right)\theta + 2\left(a^2 - b^2\right)\right]S + a\left(4b^2 - a^2\right)\Delta}{12a(a+b)(a+2b)}. \quad (A.15)$$

If $\{b > \sqrt{3}/3a\}$ or $\{\sqrt{10}/10a < b < \sqrt{3}/3\} \cap \{0 < \theta < \theta_0\}$ is satisfied, $p_p^{DD\ *} - p_j^{DU\ *} > 0$; if $\{b < \sqrt{10}/10a\}$ or $\{\sqrt{10}/10a < b < \sqrt{3}/3a\} \cap \{\theta_0 < \theta < 1\}$ is satisfied, $p_p^{DD\ *} - p^{DU\ *} < 0$.

In summary, Proposition 5 can be proved. □

Proof of Proposition 6. To compare the optimal profits in the three models, the authors compute the difference between the optimal recycler's profits as follows:

$$\pi_r^{DU\ *} - \pi_r^{S*} = \frac{-(4\theta-1)^2S^2 + 2(5-8\theta)a\Delta S + 5a^2\Delta^2}{24a} > 0, \pi_r^{DU\ *} > \pi_r^{S*}, \quad (A.16)$$

$$\pi_r^{DD\ *} - \pi_r^{DU\ *} = \frac{\left[\left(25a^2 + 54ab + 32b^2\right)\theta^2 - 4\left(5a^2 + 9ab + 4b^2\right)\theta + 2(2a+b)(a+b)\right]S^2 + 2(a+2b)[(5a+8b)\theta - 2(a+b)]a\Delta S + (a+2b)(a+4b)a^2\Delta^2}{24a(a+b)(a+2b)} > 0, \pi_r^{DD\ *} > \pi_r^{DU\ *}. \quad (A.17)$$

Then, the authors compute the difference between the optimal e-platform's profits as follows:

$$\pi_p^{DU\ *} - \pi_p^{S*} = \frac{[a\Delta + (8\theta - 5)S][7a\Delta + (8\theta + 1)S]}{144a}. \quad (A.18)$$

Setting $\theta_1 = 5S - a\Delta/8S$, based on the nonnegative condition of p_p^{S*}, $a\Delta \geq 3S$, the authors know $\theta_1 < 1/4$. When $\{\Delta < 5S/a\} \cap \{\theta < \theta_1\}$ is satisfied, $\pi_p^{DU\ *} < \pi_p^S$; otherwise, $\pi_p^{DU\ *} > \pi_p^S$.

$$\pi_p^{DD\ *} - \pi_p^{DU\ *} = \frac{\left[(32\theta - 4)(a+b) - (55a+64b)\theta^2\right]S^2 - 2[(23a+32b)\theta - 8(a+b)]a\Delta S - (7a+16b)a^2\Delta^2}{144a(a+b)} < 0, \pi_p^{DD\ *} < \pi_p^{DU\ *}, \quad (A.19)$$

$$\pi_p^{DD\ *} - \pi_p^{S*} = \frac{\left(a\theta^2 - a - b\right)S^2 + 2(a\theta - a - b)a\Delta S - ba^2\Delta^2}{16a(a+b)} < 0, \pi_p^{DD\ *} < \pi_p^{S*}. \quad (A.20)$$

Computing the difference between the optimal supply chain's profits as follows:

$$\pi^{DU*} - \pi^{S*} = \frac{\left(-32\theta^2 + 16\theta - 11\right)S^2 + 2(-16\theta + 13)a\Delta S + 37a^2\Delta^2}{144a} > 0, \pi^{DU*} > \pi^{S*}, \tag{A.21}$$

$$\pi^{DD*} - \pi^{S*} = \frac{\left[\left(7a^2 + 6ab\right)\theta^2 - 8a(a+b)\theta + (a+b)(a-2b)\right]S^2 + 2(a+2b)[(1-\theta)a + b]a\Delta S + (a+2b)(4a+5b)a^2\Delta^2}{16a(a+b)(a+2b)} > 0, \pi^{DD*} > \pi^{S*}. \tag{A.22}$$

In summary, Proposition 6 can be proved. □

Proof of Proposition 7. To compare the optimal recycling volumes in the three models, the authors compute the difference between recycling volumes as follows:

$$q^{S*} - q^{DD*} = \frac{[a\theta - a - b]S - a(2a+3b)\Delta}{4(a+b)} < 0. \tag{A.23}$$

Based on the nonnegative condition of p_p^{S*}, $a\Delta \geq 3S$, the authors derive the following:

$$q^{DU*} - q^{DD*} = \frac{[2(a+b) - (5a+8b)\theta]S - a(a+4b)\Delta}{12(a+b)} < 0, \tag{A.24}$$

$$q^{S*} - q^{DU*} = \frac{-5a\Delta + (8\theta - 5)S}{12} < 0. \tag{A.25}$$

Then, the authors have $q^{S*} < q^{DU*} < q^{DD*}$; Proposition 7 can be proved. □

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Research Article

Providing a Mathematical Routing-Inventory Model for the Drug Supply Chain Considering the Travel Time Dependence and Perishability on Multiple Graphs

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High turnover in the pharmaceutical industry, the location of placebos in urban spaces, and the high rate of corruption of products in this industry are the distinguishing features of the drug supply chain. Thus, to survive and maintain competitive advantages in the current business environment, managers are active in this background to implement the theoretical foundations of supply chain management. One of the influential areas in this category is integrated inventory management, inventory control, and vehicle routing. Therefore, this study mainly aims to analyze and define a routing problem, inventory in the drug supply chain with perishable products, and travel time dependence on multiple graphs with travel time dependence. The Box–Jenkins forecasting method has been utilized to meet the study's aim and deal with demand uncertainty. This method can identify the best pattern governing the data. Finally, the mathematical model is validated, and managerial perspectives are provided. The study results demonstrated the possibility of achieving cost-saving and reducing product spoilage. Applying the solutions of this model can provide some inherent social and environmental advantages, including reducing traffic load and emissions.

1. Introduction

In a world of growing healthcare systems with massive economies, it is essential to have some means of controlling and reducing expenses. Global healthcare expenditures are expected to rise by approximately 5.4%, from 7.724 trillion dollars in 2017 to 10.059 trillion dollars in 2022 [1, 2]. Currently, pharmaceutical products account for 20–30% of the total cost of healthcare systems [3]. This highlights the amount of cost-saving that can be achieved by reducing pharmaceutical product expenditures. According to Aptel and Pourjalili [4], managing pharmaceutical supply chains is one of the critical managerial tasks in the pharmaceutical industry. It has been suggested that integrating supply chain decisions can help achieve significant cost savings in this area.

In addition to their substantial economic size, pharmaceutical supply chains are characterized by the complexity of supply chain planning and control. Factors contributing to this complexity include production and distribution requirements such as good manufacturing practice (GMP) and good distribution practice (GDP), a considerable number of customers, and the dispersed distribution of retailers. Good manufacturing practice (GMP) is regarded as a system to ensure that products are consistently controlled and produced based on quality measures and criteria. It is mainly developed to reduce the risks involved in pharmaceutical production that cannot be easily eradicated via experimenting with the final product [5].

According to Kapoor et al. [5], other challenges of pharmaceutical supply chains include the difficulty of coordination between chain components, shortages, the expiration of products, and the requirements for safe distribution. These characteristics distinguish pharmaceutical supply chains from many other chains. Efficient and effective management of pharmaceutical supply chains can boost the development of almost all business processes in these chains. Therefore, it is crucial to use the principles of supply chain management in this industry for cost-saving and profitability improvement purposes. Essentially, a pharmaceutical supply chain is the integration of all activities related to the flow and transformation of raw materials into pharmaceutical products and their delivery to end customers, as well as the sharing and flow of information among chain components to achieve sustainable competitive advantage [6–8]. In general, pharmaceutical supply chain management problems can be divided into two domains of resource management and process development or improvement [9–11]. In a study by Mousazadeh et al. [8], they designed a four-level supply chain model for making strategic decisions regarding the construction of production centers and tactical decisions regarding the flow of materials in the medium-term planning horizon. Shang et al. [9] provided a solution for redesigning a pharmaceutical company's supply chain network to reduce costs and increase customer satisfaction. Marques et al. [10] modeled the design and manufacturing process of a new pharmaceutical product with an integrated linear programming approach. In a study by Zahiri et al. [11], they designed a resilient pharmaceutical supply chain network. Most articles in this field deal with inventory management problems at the tactical level. For example, Candan and Yazgan [12] formulated the pharmaceutical supply chain inventory problem as an integrated linear program to maximize net profit. These researchers used classical and vendor-managed inventory (VMI) problem instances to demonstrate the effectiveness of their model. Uthayakumar and Priyan [13] developed a model for integrated production-inventory planning in a two-level supply chain comprised of factories and hospitals. Jillson et al. [14] formulated a model for dynamic routing of high-value, low-volume products at the operational level. In general, articles on decision-making at the tactical level (e.g., inventory management) and at the operational level (e.g., routing) separately or together constitute a small portion of the subject literature [15, 16].

Many assumptions about classical routing problems no longer apply to the world's major cities and metropolitan areas. For example, many modern urban transportation networks are designed to have multiple viable routes between any two nodes. Also, since the traffic load depends on the time of day, the travel time will likely depend on when the trip occurs. Thus, unlike in classic routing problems, it is possible to travel longer distances in a shorter time at certain hours of the day. The problem of vehicle routing with time-dependent travels was first introduced in 1992 by Malandraki and Daskin [15], who formulated the traveling salesman problem, which is a special case of the routing problem, as a complex integer model. In their proposed model, a time window can also be considered. The main drawback of their work was that travel time was considered a stepwise function of the time of day in which the travel takes place, which can lead to the violation of the first-in-first-out (FIFO) principle. To resolve this issue, they suggested considering the notion of vehicles waiting at the nodes, which can be costly and impractical. In 2003, Ichoua et al. [16] proposed a conversion-based method to address this issue. Their method is an algorithm that converts the travel speed function into a time-dependent travel time function. In a study by Setak et al. [17], they formulated the concept of multiple paths between nodes in urban transportation networks as a multi-graph. Later, Huang et al. [18] and Patoghi et al. [19], and Tikani and Setak [20] considered this issue in their articles. Ignoring the time dependence of travel time, especially when this dependence is strong, can significantly undermine the validity, applicability, and optimality of the obtained solutions. While recent years have seen increasing interest in this domain of research in order to make vehicle routing models more realistic, there is still much work to be done in this area.

Poor inventory management in pharmaceutical supply chains can increase the spoilage rate and, therefore, the supply chain costs. In North America, for example, drug spoilage cost the pharmaceutical industry about 396 million dollars in 2018, and this cost is projected to increase at a rate of 5.4% until 2025. Considering the decreasing profit margin of pharmaceutical supply chains, it is imperative to consider these products as perishable items during planning to reduce inventory waste costs. Only a small number of articles in the pharmaceutical supply chain management field have considered inventories perishable. These include the works of Papageorgiou et al. [21] on product development and capacity planning and Shen et al. [22] on inventory management. In the field of vehicle routing, the studies that have considered perishable inventories include the studies of Le et al. [23], Coelho and Laporte [24], and Rahimi et al. [25]. Therefore, it is important to consider products as perishable items in future formulations.

One of the main assumptions of nonstochastic (deterministic) vehicle routing and inventory problems is that all parameters and data are given or obtained at certain values

[26]. This assumption has a significant drawback in that the solutions become infeasible or suboptimal when the real-world values of parameters fall outside their assumed ranges. In the literature on inventory routing for perishable products, three methods have been used to deal with uncertainty: stochastic modeling, robust modeling, and fuzzy modeling. For example, Goli and Malmir [27], and Goli and Mohammadi [28], used stochastic methods to control uncertainties in their plans. Goli et al. [29] used a robust method to control the uncertainty in demand. In an article by Rahimi et al. [25], the uncertainty was controlled by a fuzzy approach, specifically by using a probabilistic fuzzy triangular function with three sets of optimistic, pessimistic, and most probable values. As can be seen, a growing number of researchers working in the field have shown an interest in modeling uncertainty in their models to make their outputs more realistic. Nevertheless, given the varying circumstances of different problems, there is still much work to be done in this area [30, 31]. Also, the studies of Shaabani and Kamalabadi [32], Sepehri and Sazvar [33], Soysal et al. [34], Jafarkhan and Yaghoubi [35], and Crama et al. [36] have proposed new methods for dealing with uncertainty based on fuzzy numbers.

Reviewing the related studies and sources, it can be inferred that inventory routing problems are inherently np-hard, and uncertainties should be controlled without losing attention to the complexity of the model. Hence, considering the abovementioned issues surrounding pharmaceutical supply chains, to fill the existing gaps in the literature, this study attempts to provide an integrated inventory-routing model for perishable pharmaceutical products with uncertain demand and time-dependent demand travel times. The main contributions of the study to the respective field can be summarized as follows:

(1) The study utilizes integrated pharmaceutical supply chain decisions, which can substantially reduce the cost of the entire chain.

(2) The time dependence of travel time is considered on a multi-graph with a heterogeneous transport fleet, which can assist in making the model more realistic and more applicable to real-world problems.

(3) A spoilage rate for the inventory is determined, which can help reduce inventory waste costs.

(4) The Box-Jenkins forecasting methodology is taken into account to predict the uncertain demand in a case study. This method estimates the model that best explains the data while respecting the principle of parsimony (Occam's razor). Furthermore, given that the formulations are applied to a case study, the available data are employed to prevent the problem solving, which is NP-Hard, from becoming more complex and time-consuming.

2. Materials and Methods

In this section, the main assumptions of the model presented in the third section are described, which take inspiration from the real-world situation of the considered case. Basically, the proposed model is based on the pharmaceutical distribution companies' inventory and distribution management processes. This chain has two distinctive features: the perishability of products and the dispersed distribution of customers over the entire urban transportation network. The second feature, which is supposed to facilitate the accessibility of customers, i.e., pharmacies, clinics, and hospitals, leads to the dependence of travel time on the time of day when the travel takes place and also the superiority of a multiroute approach. Of course, the mentioned features do not cause the model to lose generality, and it can still be adapted to other chains such as cold supply chains and organ transplant supply chains.

Generally, the warehouse must have sufficient inventory to respond to the requested orders. This inventory level should be maintained according to projected demand and the spoilage rate of products. Orders are loaded onto the heterogeneous transport fleet at the beginning of the delivery horizon. The route sequences and active routes for loaded vehicles are determined according to the traffic load around customers during the day when the trip takes place. The vehicles return to the warehouse after serving the last customer.

This problem is formulated on a complete multigraph G(N, A), where N represents the set of nodes and A represents the set of edges connecting the nodes. Each edge is denoted by (i, j, p), representing the p-th path between the nodes i and j. Node 0 represents the supplier, and the remaining nodes represent the customers. The set of vehicles is denoted by $vt \in \{1, 2, \ldots, V\}$. Each type of vehicle has a certain capacity, denoted by cap_{vt}. The number of vehicles in the warehouse is denoted by k_{vt}. Each vehicle can take only a single route in each time period of the planning horizon. Also, each customer can be served by only one vehicle in each time period of the planning horizon. The service time is denoted by s_i. All activated vehicles start their trips from the warehouse simultaneously at the beginning of the delivery horizon and return to the warehouse at the end of their service. An inventory holding cost of h_i is incurred for each unit of product that is stored in each node in each period. Since each product has a limited shelf life, wr_i percent of products spoil in each period. For each unit of spoiled product, the system incurs a cost denoted by pr, which can be as high as the product's unit price.

Travel time on each edge depends on the time of day when the trip takes place. So as to satisfy the FIFO principle, the travel speed function was converted to travel time. The main reason for this action is that the mentioned conversion makes the model more realistic and accurate, given the fact that the change in travel speed is more tangible and substantial.

The purpose of the model is to determine the optimal delivery routes, the optimal quantity of goods to be delivered to each customer, and the optimal inventory level of each node in each planning horizon period such that routing, inventory, and spoilage costs are minimized. It is assumed that routing costs are comprised of a variable time-dependent cost and a fixed cost for using the vehicle.

2.1. Assumptions. To carry out this study, it is assumed that the entire demand in each period must be fully met. Having historical demand data, the Box–Jenkins forecasting method is utilized to predict the demand in the future periods of the planning horizon for use in the model table1.

2.2. Objective Function. The objective function of the model is to minimize costs. These costs are divided into two categories: routing costs and inventory costs. Routing costs include the fixed cost of using the vehicles, which depends on the type of vehicle, and a variable cost, which depends on the number of hours the vehicle is to be used over the course of the planning horizon. Inventory costs consist of inventory holding costs and product spoilage costs. Therefore, the objective function is formulated as follows:

$$\min Z = \sum_{vt=1}^{V} fc_{vt}.\left(\sum_{i=0}^{N}\sum_{\substack{j=0\\ i\neq j}}^{N}\sum_{m=1}^{M}\sum_{pt=1}^{T}\sum_{p=1}^{P} x_{i,j,vt}^{p,m,pt}\right) + \sum_{vt=1}^{V} VC_{vt}.\left(\sum_{i=1}^{N}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{pt=1}^{T}\left(\theta_{i,0,vt}^{p,m} dt_{i,0,vt}^{p,m,pt}\right) + \left(\eta_{i,j,vt}^{p,m}.x_{i,0,vt}^{p,m,pt}\right)\right) + \sum_{i=0}^{N}\left(h(i).\left(\sum_{pt=1}^{T} il_i^{pt}\right)\right) + pr.\left(\sum_{i=0}^{N}\sum_{pt=1}^{T} was_i^{pt}\right). \tag{1}$$

2.3. Model Constraints. The objective function formulated in the previous subsection is based on the following constraints:

$$il_0^{pt} = il_0^{pt-1} + rpd_{pt} - was_0^{pt} - \sum_{j=1}^{N} q_j^{pt} \quad \frac{\forall pt \in T}{\{1\}}, \tag{2}$$

$$il_0^1 = rpd_1 - was_0^1 - \sum_{i=1}^{N} q_i^1, \tag{3}$$

$$il_0^{pt} = il_0^{pt-1} + q_i^{pt} - was_0^{pt} - de\ m_i^{pt} \quad \frac{\forall pt \in T}{\{1\}}, \quad \frac{i \in N}{\{0\}}, \tag{4}$$

$$il_i^1 = iil_i + q_i^{pt} - was_i^{pt} - de\ m_i^{pt} \quad \frac{\forall i \in N}{\{0\}}, \tag{5}$$

$$il_i^{pt} \leq cap_i \quad \forall i \in N, \quad pt \in T, \tag{6}$$

$$was_i^{pt} = wr_i.il_i^{pt} \quad \forall i \in N, \quad pt \in T, \tag{7}$$

$$rpd_{pt} = \sum_{i=0}^{N} was_i^{pt} + \sum_{i=1}^{N} de\ m_i^{pt} \quad \forall pt \in T, \tag{8}$$

$$\sum_{j=1}^{N} x_{0,j}^{vt,pt} \le k_{vt} \quad \forall vt \in V, \quad pt \in T, \tag{9}$$

$$\sum_{i=0}^{N} \sum_{vt=1}^{V} x_{i,j}^{vt,pt} = 1 \quad \frac{\forall j \in N}{\{0\}}, \quad pt \in T, i \ne j, \tag{10}$$

$$\sum_{j=0}^{N} \sum_{vt=1}^{V} x_{i,j}^{vt,pt} = 1 \quad \frac{\forall i \in N}{\{0\}}, \quad pt \in T, i \ne j, \tag{11}$$

$$\sum_{i=0}^{N} x_{i,j}^{vt,pt} = \sum_{k=0}^{N} x_{j,k}^{vt,pt} \quad \frac{\forall j \in N}{\{0\}}, \quad vt \in V, pt \ne T, \tag{12}$$

$$\sum_{p=1}^{P} x_{i,j,vt}^{p,pt} = x_{i,j}^{vt,pt} \quad \forall i, j \in N, \quad vt \in V, pt \in T, \tag{13}$$

$$\sum_{m=1}^{M} x_{i,j,vt}^{p,m,pt} = x_{i,j,vt}^{p,pt} \quad \forall i, j \in N, i \ne j, \quad p \in P, vt \in V, pt \in T, \tag{14}$$

$$x_{i,i,vt}^{p,m,pt} = 0 \quad \forall i \in N, vt \in V, \quad p \in P, m \in M, pt \in T, \tag{15}$$

$$\sum_{i=0}^{N} f_{i,j}^{pt} - \sum_{k=0}^{N} f_{j,k}^{pt} = q_j^{pt} \quad \frac{\forall j \in N}{\{0\}}, \quad pt \in T, \tag{16}$$

$$\sum_{p=1}^{P} \sum_{vt=1}^{V} f_{i,j,vt}^{p,pt} = f_{i,j}^{pt} \quad \forall i, j \in N, i \ne j, \quad pt \in T, \tag{17}$$

$$\begin{aligned} & q_j^{pt} \le f_{i,j,vv}^{p,pt} \le cap_{vt} - q_i^{pt} \quad \forall i, j \in N, i \ne j, \\ & p \in P, vt \in V, pt \in T \end{aligned} \tag{18}$$

$$dt_{0,j,vt}^{p,m,pt} = L.x_{0,j,vt}^{p,m,pt} \quad \frac{\forall j \in N}{\{0\}}, \quad vt \in V, p \in P, m \in M, pt \in T, \tag{19}$$

$$b_{i,j,vt}^{p,m}.x_{i,j,vt}^{p,m,pt} \le dt_{i,j,vt}^{p,m,pt} \le b_{i,j,vt}^{p,m+1}.x_{i,j,vt}^{p,m,pt} \quad \forall i, j \in N, i \ne j, vt \in V, \quad p \in P, m \in M, pt \in T, \tag{20}$$

$$\sum_{i=0}^{N}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{vt=1}^{V}\left(\theta_{i,j,vt}^{p,m}.dt_{i,j,vt}^{p,m,pt}+\eta_{i,j,vt}^{p,m}.x_{i,j,vt}^{p,m,pt}\right)+\sum_{i=0}^{N}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{vt=1}^{V}dt_{i,j,vt}^{p,m,pt}+\sum_{i=0}^{N}\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{vt=1}^{V}dt_{j,k,vt}^{p,m,pt}\quad\frac{\forall j\in N}{\{0\}},\quad j\neq i, j\neq k, pt\in T, \tag{21}$$

$$\sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{vt=1}^{V}\left(\theta_{i,o,vt}^{p,m}.dt_{i,o,vt}^{p,m,pt}+\eta_{i,o,vt}^{p,m}.x_{i,o,vt}^{p,m,pt}\right)\leq U\quad\frac{\forall i\in N}{\{0\}}\quad pt\in T, \tag{22}$$

$$Z, dt_{i,j,vt}^{p,m,pt}, f_{i,j}^{pt}, f_{i,j}^{p,pt}, f_{i,j,vt}^{p,pt}, il_i^{pt}, was_i^{pt}, q_i^{pt}, rpd_{pt}\geq 0, \tag{23}$$

$$x_{i,j}^{vt,pt}, x_{i,j,vt}^{p,pt}, x_{i,j,vt}^{p,m,pt}=o\text{ or }l. \tag{24}$$

Constraint (1) maintains the inventory balance of the central warehouse. Constraint (2) computes the inventory level at the end of the first period based on the assumption that the inventory level at the beginning of the planning horizon is zero. Constraint (3) maintains the inventory balance of customer warehouses. Constraint (4) determines the inventory level of customers at the end of the first period, assuming that their inventory is empty at the beginning of the planning horizon. Constraint (5) limits the capacity of warehouses. Constraint (6) calculates the amount of product spoiled in warehouses. Constraint (7) determines the amount of product received in the central warehouse in each period. Constraint (8) limits the number of activated vehicles of any type to the number of vehicles of that type that are available. Constraints (9) and (10) ensure that each node is visited exactly once. Constraint (11) forces activated vehicles to depart toward another customer or the central warehouse upon serving a customer. Constraint (12) states that if a vehicle of type vt is selected to travel between two nodes (i, j), it will travel only one route (path p) between the two nodes. Constraint (13) states that if a path p between two nodes (i, j) is activated for a vehicle of type vt, this travel must take place exactly in the m-th time interval ($[b_{i,j,vt}^{p,m}, b_{i,j,vt}^{p,m+1}]$). Constraint (14) prevents the formation of loops. Constraint (15) balances the flow of products between nodes to satisfy customer demand. Constraint (16) ensures that products are transported on a single route between (i, j). Constraint (17) makes sure that the capacity of each type of vehicle is respected while serving customers. Constraint (18) states that no vehicle can leave the central warehouse before the start of the delivery time horizon. Constraint (19) limits the time of departure from node i toward node j on path p to the m-th time interval specified in Constraint (20). In Constraint (21), the time of departure from each node is computed by summing the time of departure from the previous node with the travel time between the two nodes and the service time of that node. Constraint (22) states that the delivery to customers must be completed before the end of the delivery time horizon. Constraints (23) and (24) specify the type of variables.

2.4. Solution Procedure. The proposed routing-inventory model has complexities in various respects. On the one hand, the dependence of travel time on the time of day and the path between the nodes is available. This issue can be resolved by utilizing a stepwise time-dependent travel time function. Nonetheless, applying this approach results in a violation of the FIFO principle. On the other hand, we have to cope with uncertainty in the demand parameter without adding to the complexity of the model. To resolve these issues, a two-step approach was proposed. In the first step, the time-dependent travel time function was computed while observing the FIFO principle for each route. The output of this step will be a time-dependent routing-inventory model. In the next step, the Box–Jenkins forecasting method was employed to predict the demand. Adopting this approach prevents the model from getting more complex while observing the principle of parsimony. The outputs of this procedure will be the inputs of the model provided in Section 3.

2.5. Time-dependent Travel Time Function Calculations. Considering a constant length for time-dependent travel time leads to the violation of the FIFO principle, which states that if vehicle A departs from node i toward node j earlier than an identical vehicle like B does the same, vehicle A must reach its destination sooner. In an article by Ichoua et al. [16], they presented a technique for solving this problem based on the decomposition of travel speed over consecutive periods for each day. In this way, they divided the day into multiple time periods over which travel speed remains constant. This approach gives a time-dependent travel speed function in the form of a stepwise function. Thus, travel time can be calculated from the travel speed function with an algorithm based on the decomposition of travel speed over consecutive periods as described below.

It is assumed that the length of the delivery time horizon [L, U] is divided into r intervals with endpoints $T=\{t_1, t_2, \ldots, t_r\}$, where $t_1=L$ and $t_{r+1}=u$, such that speed over the interval r remains constant at v_r. Since there can be more than one route between every two nodes, the

Table 1: Indices, variables, and parameters of the proposed model.

Indices and sets	
k, j, i	Index for nodes; node 0 represents the central warehouse and other nodes represent customers.
Pt	Index of periods of the planning horizon
vt	Index of vehicle types
P	Index of the p-th path between two nodes
r	The number of intervals into which the delivery time horizon is divided such that the travel speed on the route remains constant in each interval.
m	Index of intervals in which travel time is a piecewise linear function with a fixed slope in each interval.
Parameters	
$[b_{i,j,vt}^{p,m}, b_{i,j,vt}^{p,m+1}]$	The m-th interval of the travel time function
$[t_{i,j}^{p,r}, t_{i,j}^{p,r+1}]$	The r-th interval of the travel speed function
$v_{i,j,vt}^{p,r}$	Travel speed on path p between nodes i and j for vehicle vt in interval r
$d_{i,j}^{p}$	The distance between nodes i and j via path p
$\text{dep}_{i,j,vt}^{p,r}$	The time that vehicle vt needs to depart from node i toward node j in order to arrive at its destination at a specified time via path p in interval r
$\text{ariv}_{i,j,vt}^{p,m}$	The time that vehicle vt arrives at node j via path p if it departs from node i in interval m.
$\text{trt}_{i,j,vt}^{p,m}$	Travel time from node i to node j via path p for vehicle vt if it departs from node i in interval m
$\theta_{i,j,vt}^{p,m}$	The slope of the piecewise linear function of travel time for the node pair (i, j), vehicle vt, path p, and interval m
$\eta_{i,j,vt}^{p,m}$	The intercept of the piecewise linear function of travel time for the node pair (i, j), vehicle vt, path p, and interval m
S_i	Service time for customer i
dem_i^{pt}	The demand of customer i in period pt
cap_{vt}	The capacity of a vehicle vt
cap_i	Warehousing capacity of node i
fc_{vt}	Fixed cost of using vehicle vt
VC_{vt}	The time-dependent variable of using vehicle vt
h_i	Cost of storing the product in node i for one period
Pr	The unit price of the product
wr_i	Product spoilage rate when stored in node i
iil_i	Initial inventory level of node i at the beginning of the planning horizon (it is assumed that the initial inventory level of the central warehouse is 0).
k_{vt}	Number of vehicles of type vt
$[L, U]$	Length of the delivery time horizon in each period of the planning horizon
Variables	
Z	Objective function value
$x_{i,j}^{vt,pt}$	=1 if the edge connecting node i to node j is selected as the optimal route for vehicle vt in period pt; = 0 otherwise
$x_{i,j,vt}^{p,pt}$	=1 if the edge connecting node i to node j via path p is selected as the optimal route for vehicle vt in period pt;=0 otherwise
$x_{i,j,vt}^{p,m,pt}$	=1 if the edge connecting node i to node j via path p is selected as the optimal route for vehicle vt in interval m in period pt; = 0 otherwise
$dt_{i,j,vt}^{p,m,pt}$	Time of departure of vehicle vt from node i toward node j via path p in interval m in period pt
$f_{i,j}^{pt}$	The amount of product transported on the activated edge connecting node i to node j in period pt
$f_{i,j}^{p,pt}$	The amount of product transported on the activated edge connecting node i to node j via path p in period pt
$f_{i,j,vt}^{p,pt}$	The amount of product transported by vehicle vt on the activated edge connecting node i to node j via path p in period pt
il_i^{pt}	Inventory level of node i at the end of period pt
was_i^{pt}	The amount of product spoiled in the warehouse of node i during the period pt
q_i^{pt}	The amount of product delivered to customer i in period pt
rpd_{pt}	The amount of product arriving at the central warehouse during the period pt

travel time function corresponding to the travel speed function for each route will be a piecewise linear function.

2.6. Travel Speed Conversion. The main idea of this method is that vehicles do not travel the entire route between two nodes at a constant speed but instead change their speed at two or more time intervals. For example, a vehicle that starts its trip from node i to node j at the time t_0 of the day may travel one part of the route (d_1) at speed v_1 over time $t_1 - t_0$, travel another part of the route (d_2) at speed v_2 over time $t_2 - t_1$, and travel the remainder of the route $(d_3 = d - (d_2 + d_1))$ at speed v_3.

2.7. Travel Time Calculation with the Travel Speed Function. For a vehicle leaving node i at a time $t_0 \in T_r = [t_{i,j}^{p,r}, t_{i,j}^{p,r+1}]$ to reach node j via path p, the travel time is calculated through the following procedure:

1-1- Set t to t_0.
1-2- Set d to d_{ij}.
1-3-Set t' to $t + (d/v_r)$.
2-Perform the following loop as long as $t' > t_{ij}^{pr}$.
2-1-Set d to $d - v_r(t_{ij}^{p,r+1} - t)$.
2-2-Set t to $t_{ij}^{p,r+1}$.
2-3-Set t' to $t + (d/v_{r+1})$.
2-4-Set r to $r + 1$.
3-Travel time = $(t' - t_0)$.

2.8. Box-Jenkins Forecasting Method. A time series is an ordered sequence of data over time. One inherent characteristic of time series is the dependence or correlation of observations, which makes the order of observations quite important. Hence, statistical methods that operate based on the assumption that data are independent over time are not applicable to time series. The statistical methodology developed for working with and interpreting time series is called time series analysis. Typically, the goal of time series analysis is to describe, model, or predict data or examine the dynamics of a variable over time. In the current study, the uncertainty in demand is modeled utilizing the Box–Jenkins forecasting methodology, involving fitting an auto-regressive integrated moving average (ARIMA) model [37–39]. An ARIMA model itself is characterized by its autoregressive and moving average processes and a degree of integration. The moving average process models the observed time series (Z_t) as a linear combination of a sequence of uncorrelated random variables. The autoregressive process models the present value of the time series as a function of its previous values plus a random effect. Integration is used for time series that do not have a fixed mean to make analyses more reliable. Therefore, if a time series is stationary after d times of first-order differencing and is modeled as ARMA (p, q), then the original time series is an autoregressive integrated moving average time series in the form of ARIMA (p, d, q).

3. Results and Discussion

After implementing the Box–Jenkins method in EViews software for the demand time series of one customer, the model ARIMA (0,0,1) was chosen for fitting and forecasting. Therefore, the fit equation for the independent variable demand was obtained as follows:

$$(1 - B)^1 \text{dem}_t = q_0 + q_1(B)a_t. \tag{25}$$

Using the software, the forecasts for the first difference were obtained as shown in Figure 1:

The red, green, and blue lines in this figure indicate the actual, forecasted, and residual values, respectively. The demand forecasts obtained for the first, second, and third periods of the planning horizon are all 37 units.

The model presented in Section 3 was solved with GAMS software using the complex solver on a computer system with a 2.53-GHz CPU and 8 GB of RAM. The studied supply chain has two levels, with one central warehouse on the first level and 10 customers on the second level. The transport fleet consists of two types of vehicles (8-ton and 10-ton trucks). In the solution obtained after 1000 seconds, the objective function value is 3324.994 (thousand tomans). The optimal route is constructed such that the expected demand is met.

Regarding the inventory levels of nodes, only node 6 had kept 1 unit of inventory at the end of period 2. The amount of product received by each node was also determined based on the change in the vehicle load and after visiting the node.

In the following, we use the solutions of the model to provide some analyses and interpretations that might benefit managers and researchers interested in the field. If we assume that the travel time does not depend on the time of day in which the trip takes place and also does not define any time constraint for the service, the order and sequence of service will be as follows (Figures 2–4):

Under this assumption, the total distance traveled will be 375.4 (km), which is less than the 450.75 (km) obtained in the original solution. However, since time-dependent variable costs make up a major portion of the total cost, one can surmise that a reduction in the routing cost can offset the increase in distance traveled. Likewise, considering the social and environmental impacts of decreasing the travel length of distribution vehicles, such as reduced traffic load and thus reduced air pollution and travel time of citizens, managers of distribution companies might be able to make a profit by spending less on the penalties imposed by the government or earning more from the rewards offered by the government for traffic control purposes.

As the solutions of the model demonstrate, in certain instances, the model has chosen the longer path between the two nodes. For example, in the first period, the model has chosen the slightly longer second route between nodes 1 and 11 (the 16.5 km long second route rather than the 15.1 km long first route).

While this may not conform to the classical view of cost minimization, with a more holistic view of the matter, including the environmental and social benefits that lie within this choice, one can understand the importance of minimizing the total time of tours. This travel time reduction makes it possible to serve more customers within the bounds of the delivery horizon and also reduces time-dependent variable costs such as driver wages, which can make up a large portion of the routing costs.

Therefore, managers working in the field of distribution should arrange the order in which customers are served such that those positioned in crowded areas with heavy traffic during peak hours are visited only during off-peak hours (e.g., the middle of the day as opposed to the early hours), when they can be accessed more quickly and via less busy roads. Moreover, this is evident in our solutions in the sense that customers who were located in the city center, where traffic is heavy for a few hours around the start and end of office hours (during peak hours), were served in the middle hours of the day, and customers located on the outskirts of the city were served near the beginning or end of the delivery horizon.

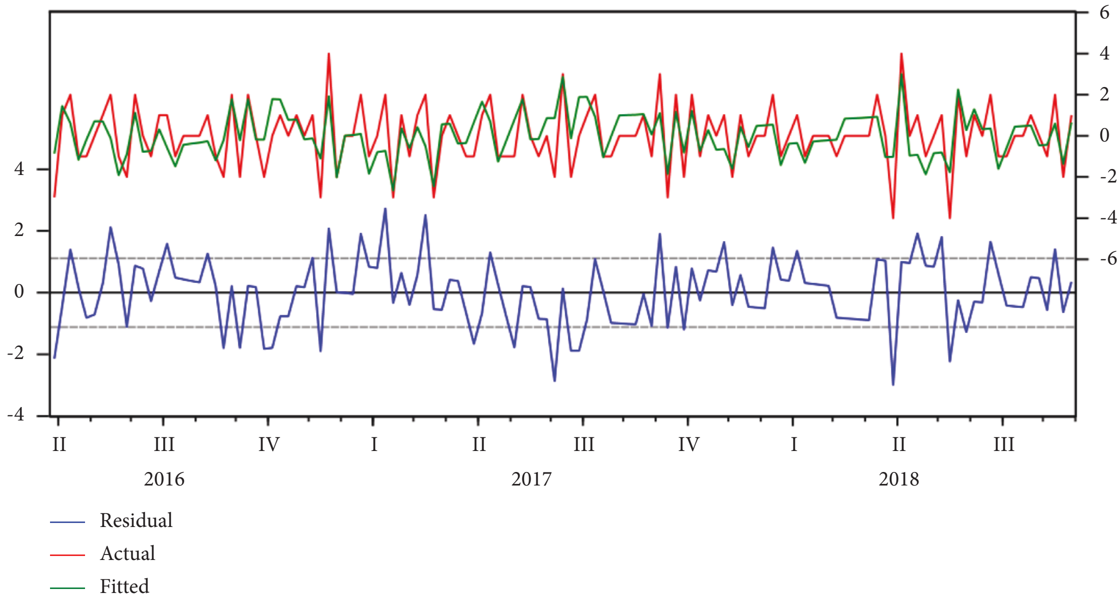

Figure 1: Forecasts for the first difference of customer 6.

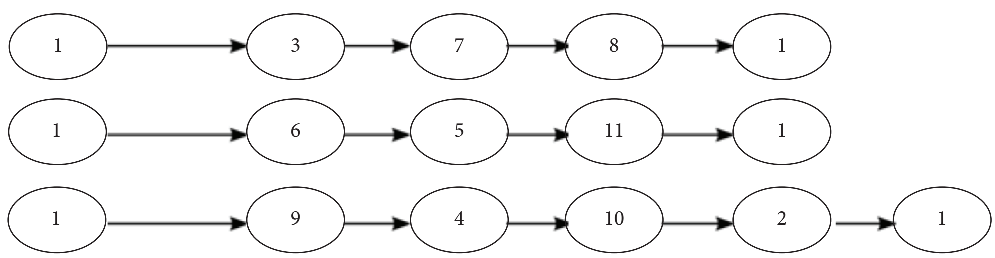

Figure 2: Details of the routes formed in the first period.

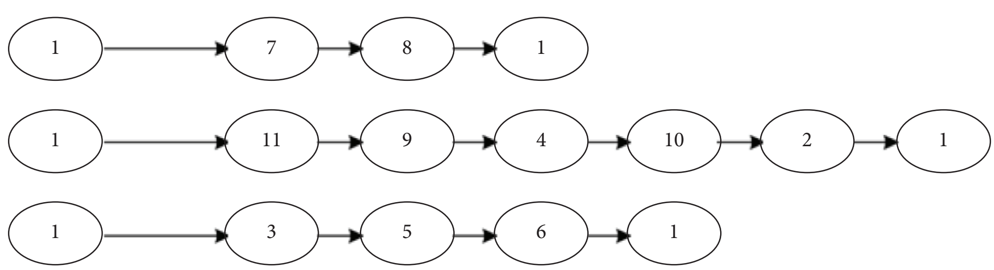

Figure 3: Details of the routes formed in the second period.

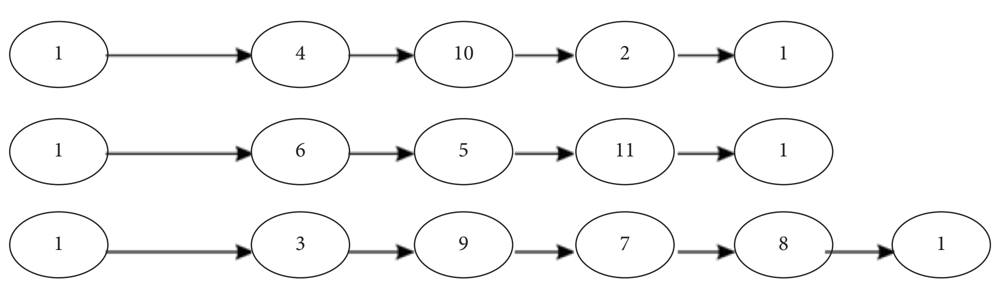

Figure 4: Details of the routes formed in the third period.

As can be seen, costs are almost linearly related to the spoilage rate (i.e., the lower the spoilage rate, the lower the costs). For example, reducing the spoilage rate by half will reduce the inventory routing cost by 1.7%, and reducing it to 0.2 of its current rate will reduce the inventory routing costs by 0.6%.

4. Conclusion

The pharmaceutical industry is immense, with a broad range of logistical operations. Considering this industry's ongoing technological and competitive developments, pharmaceutical companies must uphold modern supply chain management principles to maintain their competitive advantages and survive. As in most other supply chains, inventory holding and distribution costs account for a large portion of pharmaceutical supply chain costs. Thus, any cost reduction in these two areas can lead to significant cost savings for these companies. This study modeled an inventory-routing problem for perishable pharmaceutical products with time-dependent travel times and uncertain demand on a multigraph. The reason for adopting the multigraph approach and defining the travel time as a function of the time of day on which the trip occurs (i.e., traffic volume) was to make the proposed model more aligned with real-world pharmaceutical product distribution networks. The model was formulated to guarantee the FIFO property with a conversion of the travel speed function to travel time. The Box–Jenkins forecasting methodology was employed to control the uncertainty in demand. Given the fact that most drugs have a fixed shelf life, perishability was modeled by determining a variable representing the spoilage rate. To validate the proposed model and demonstrate its applicability, it was applied to the actual data of Asia Pharmaceutical Distribution Company and, mainly, the demand data it has recorded since 2017. The solution results indicated the possibility of achieving cost-saving and reducing product spoilage. The total cost of the supply chain for this particular case was computed to 3324,994 monetary units. Furthermore, adopting this model's solutions brings about some inherent social and environmental benefits, such as relieving traffic load and emission.

Regarding future studies in the respective arena, the recommendations below are provided:

(1) Employing environmental and social criteria to analyze the effect of utilizing this type of inventory routing problem on the total traffic load, emission, and product spoilage.

(2) Modeling perishability as the residual life of products based on their age.

(3) Considering other causes of the time dependence of travel time, including weather circumstances and traffic accidents in the decisions and examining their effect on the solutions.

Data Availability

Data will be available upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Review Article

Analysis of Factors Affecting the Success of Sustainable Development Projects with the Help of Machine Learning Tools

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Sustainable development projects are a group of development projects created with the aim of sustainable urban growth and development. To achieve development, it is essential to pay attention to the existence of projects. The point to consider is the threat of these expensive assets by all kinds of risks, such as floods, earthquakes, wars, mistakes, and price fluctuations, during the life cycle of projects from the beginning of their idea to the end of their useful life. Hence, the main objective of the study is to analyze the criteria and factors of project success and different machine learning strategies to achieve success and predict specific construction performance. To meet that aim, the research employs the descriptive approach, and analytical and logical aspects are derived from various sources such as research articles, published materials, online websites, books, and articles. The study's results reveal that employing machine learning tools and algorithms to create a link between project success factors and criteria and prediction can bring multiple advantages, including high accuracy, ease of use, and inference for decision-making. It can be concluded that algorithmic solutions could be integrated in a manner that project managers can adequately utilize to enhance project success by eliminating potential risks and guiding the project toward attaining its objectives.

1. Introduction

Despite various and multiple successful projects in this area, there is no consensus about a single and comprehensive definition of project success due to different, and often contradictory, objectives of stakeholders involved in a project [1, 2]. Some studies have defined success by determining some criteria and indices, while others have introduced a set of factors affecting the success of a project. Accordingly, project-based organizations can better deal with the challenges of a project and successfully implement the project by understanding these factors [3–5]. In addition, a strategy extracted from the set of factors for project success can be used as a beneficial tool for project selection by organizations and decision-making. Project success strategies can play a significant role in managers' correct and informed decision-making [4, 5]. The present study aimed to evaluate and accurately understand the concept of project success to assess the impact of using machine learning, which is one of the artificial intelligence exact methods, on the success of construction projects.

Organizations need continuous performance improvement to maintain their existence, eliminate their weaknesses and improve their strengths [2, 5]. Prediction of success is an essential factor for organizations in addition to expanding evaluation. Showing a bright future of the project's results based on conditions governing the influential factors of the project has always been demanded by beneficiaries of the project. This is extremely important for organizations that must constantly choose from the existing opportunities, choices that must be made optimally and as the safest choice due to resource limitations [3, 6, 7]. Project success strategies can play a considerable role in managers' informed decision-making. In addition, this can help determine the deviation from the project's path to achieve the goals with the specified restrictions and warn the stakeholders of these deviations by continuous project monitoring [4, 5]. While this tool is more accurate and used based on criteria and indices, it will be more accurate in case of planning to eliminate its defects and improve its performance [8–11]. Moreover, the construction part is a knowledge-based field surrounded by a large amount of objective, heterogeneous, and interdependent data surrounding abstract knowledge. In most cases, construction organizations fail to use the opportunity due to access to the data, although the conventional project performance and success analysis methods, which highly depend on subjective data sources or do not take variable dependencies in the data into account and are generally used in this regard [12–15].

Reviewing the recent studies, no doubt utilizing machine learning data analysis tools can significantly benefit the company by improving the performance of construction projects as one of the main indices of a successful project. Hence, the objectives of the study can be summarized as follows:

(i) Understanding machine learning project lifecycle

(ii) Recognizing the cause and impact of machine learning on project success

(iii) Identifying the benefits, challenges, and vision of machine learning in project success

(iv) Determining the factors and indices affecting project success

This present research can greatly contribute to the arena of construction studies by demonstrating machine learning as a project performance evaluation method. Moreover, the results of the study can permit construction companies to evade evidence-based knowledge and data-backed decisions to avert future construction failure.

2. Methodology

The present study attempted to analyze the criteria and contributing factors of project success and various machine learning approaches to attain success in critical project stages.

The present study is regarded as a developmental study. Generally speaking, development research is defined as studies carried out on the basis of knowledge. This kind of study is performed based on experiences from previous research and is performed in order to innovate and improve products. Therefore, the study is based on secondary data.

Moreover, the research is descriptive since it primarily focuses on “what” is the subject of the research. Furthermore, analytical and logical aspects have been derived from various sources such as related and updated research articles, published materials, online websites, books, and articles.

3. Results

The human desire for development and progress has always been an intrinsic demand. In fact, this factor is the source of success-related activities and achievements of human beings. Success is a degree of meeting expectations and objectives that might have financial, cultural, social, technical, and professional aspects. Today, projects are considerably increasing in most organizations, which has increased the importance of answering the question of “what is the meaning of project success?” [4, 16, 17].

3.1. Project Success from the Perspective of Sciences. The term “project success” in project management was first introduced in the early 1900s with three main triangles of time, cost, and quality, showing its impacts in this triangle. For 50 years, project success depended on achieving the iron triangle of time, cost, and quality. However, it went beyond that concept in the 60s and 70s, and organizational management methods were added to it [5]. Nonetheless, the project management triangle with three variables of scheduling, cost, and technical performance has become the best tool for identifying and determining the success or failure of the project. However, risk capacity and management have been identified as some of the main components of project success assessment. Project success is formed from two micros (i.e., time, quality, performance, and safety) and micro (i.e., time, satisfaction, utility, and operations) perspectives [6, 18]. According to Ashley, project success is achieving the best results in cost, scheduling, quality, safety, and satisfaction of involved people compared to what was expected or observed in practice [19–22]. Project success is an abstract concept, and it is challenging to determine whether a project has succeeded or failed [8]. Project success means that all parties involved in the project achieve their projected benefits in the end. Otherwise, the lack of benefit of one of the parties upsets the balance, which endangers the entire project [9, 23]. Since project and project management are both complex phenomena, the success criteria must also reflect this issue. This means that from the perspective of project success, both project results and project management should be considered. The success of project results focuses on the project’s outcome, whether the project’s result, created by the project, meets the needs of the most important stakeholders [24–26]. Therefore, its success focuses on the appropriate use of resources and appropriate management of beneficiaries. Thus, project management success includes project delivery efficiency, while project success indicates project delivery effectiveness [10]. In fact, project success involves separate judgments in three separate layers and not just one. Two of these items are related to the performance of the two main players, i.e., project manager and project owner, respectively. In contrast, the third one is related to the investment performance presented by the project from the perspective of the investor [11]. A successful project sustainably generates value. Generating value entails working with quality and creating benefits for the customer [12]. Table 1 demonstrates the course of adequate definitions of success during 1985–2020.

3.2. Project Success Criteria and Factors. One of the critical issues of project management is to identify the success factors of construction projects. Generally, there exist four different success factors in construction projects. The initial

Table 1: The course of effective definitions of success during 1985–2020.

Description	Source
Everything must go as desired. Predicting all necessities and having access to sufficient sources to achieve demands in a timely manner	[1, 3]
Achieving outcomes more desirably than what was anticipated or at least acquiring normal results in time, cost, quality program, satisfaction, and safety of members	[4]
If the project is performed based on the characteristics of technical performance and mission, and if a high level of satisfaction is achieved among the key individuals of the parent company, customer organization, and project team and users.	[7, 11]
A project is successfully finished if: (1) it is finished on time (temporal criterion), (2) it is finished based on the desired budget (monetary criterion), (3) it primarily achieves all primary goals (effectiveness criterion), and (4) it is acceptable and used by customers who demanded it (customer satisfaction criterion).	[5, 6]
Project success is one of the following: (1) completion on time and with a projected budget and desirable advantages for the company, (2) production manufacturing with high design quality and consulting services, and (4) meeting the demands of beneficiaries.	[8]
Project success is based on five factors: (1) project is finished on time, (2) project is finished with the predetermined budget, (3) project is finished at the expected level of quality, (4) project is accepted by customers, and (5) results permit the contractor to utilize customers as references.	[9, 10]
Project success is a set of principles and standards completed with favorable results in comparison with several predetermined characteristics. Project success factors are processes that must go well to ensure success for the manager and the organization.	[12]
Project success definitions depend on the type, magnitude, complexity, and involved individuals. Some of the critical factors of the project may not be transferable to another project due to environmental variables, the proj'ct's nature, the nature of the involved organization, and the priorities of project objectives.	[2, 13]
The difference between the success factors and success criterion is of considerable importance. Success criteria are those which are used to judge the project's success or failure. Meanwhile, success factors are those entering the management system that indirectly or directly affects the project's success.	[3, 5]
The reasons for the success of projects have taken a slower path in achieving a standard or even a certain acceptable operational framework. In this regard, achieving a specific formula with an easy method seems ideal.	[14, 15]
Project success focuses on the appropriate use of resources and proper management of beneficiaries. Therefore, it shows the effectiveness of project delivery.	[7, 16]
A project is successful when its results match its goals and are achieved on time without going over budget. "Project success" consists of separate judgments in three separate layers, namely the project manager, the project owner, and capital performance presented by the project from the investor's point of view.	[17]
A successful project is one that sustainably generates value. Generating value entails working with quality and creating benefits for the customer.	[18]

factor is meeting the design's objectives, referring to the contract signed with the customer. The second one is the advantage to the end users, referring to the advantage to the clients from the project end products. The third one is the advantage to the developing association, referring to the benefit achieved by the developing association as a result of performing the project. The final factor is the advantage of the national technological infrastructure and the 'company's technological infrastructure involved in the development process. The combination of all of those factors presents the general evaluation of project success [13, 17, 27]. A lack of sufficient and comprehensive understanding of a 'project's success factors complicates the 'project's control, monitoring, and performance. Therefore, it is vital to distinguish between success metrics and success factors. Success criteria are those factors based on which the success or failure of a project is judged. Meanwhile, success factors are those entering the management system that can lead to project success directly or indirectly [8, 27]. Success factors are environmental, realities, and affective factors that can affect the project's outputs. These factors can accelerate the pace of a project or cause problems for the project. They can lead to the project's failure but cannot be considered a basis for project evaluation [5]. Project success factors are components that must go well to guarantee the manager and organization's success [13]. In a study by Nguyen et al., five key success factors were extracted from 20 factors, which included competent project manager, providing sufficient financial resources until the end of the project, competent and multi-disciplinary project team, commitment to the project, and access to resources [28–30]. Evidently, there is a connection between project quality and project performance. Therefore, people must focus on quality to have project success. In addition, organizations must focus on teams, organization, project management, product, environment, as well as related technical factors and resources to succeed [15]. American scholars have identified the following factors for project success: satisfaction of beneficiaries, the realization of project goals, not going over the project budget, finishing the project on time, added value, having access to the required quality, and professional satisfaction of the project team [16]. Given the growth of construction projects, many studies have focused on the success factors of these projects in the past few years. Since there is still no consensus about the matter, the opinions of researchers from various countries are evaluated. By analyzing these ideas, we reach relative results: (1) time, cost, and quality are the main criteria for project success, and (2) satisfaction of beneficiaries, especially customers, is considered the second criterion of project success [17]. Project success criteria that are extremely important include value, team success, quality, commercial interests, and constraints [12]. Table 2 presents the evolution of success criteria over different decades.

Considering Table 2 and identifying the success criteria of projects according to the type of projects by managers, employers, and executives can provide a good framework for evaluating and reviewing project outputs for them. Moreover, understanding the success factors of projects can help manage the proper allocation of resources throughout the life cycle of the project.

3.3. Review and Collection of Project Success Criteria and Factors. There should be a distinction between the two concepts of success criteria and success factors. First, the criteria for success must be identified, and then success factors should be determined to increase the probability of project success. The basis of the information gathering step was the data collected from the library, digital, and other resources related to the literature on the subject. Accordingly, it was crucial to evaluate success criteria to predict success and to assess the level of realization of factors required for success. Overall, 23 criteria and 47 factors were identified for success following and collecting data from library resources and interviewing at least 110 experts in the field. A final review was conducted due to the similarity or at least conceptual commonality of several items or low importance of some of them to purify the criteria and factors. It is also notable that numerous different factors were extracted from literature. Therefore, each factor should have at least conceptual overlap with other factors. On the other hand, it must have sufficient comprehensiveness to convey concepts. In other words, some of the factors mentioned in several previous studies can be divided into several groups, leading to misinterpretation by the audience. Therefore, each factor must be correctly grouped to have a common border with other factors. This consensus led to summarizing 23 criteria and 47 factors into 16 and 33 critical criteria and factors, respectively, based on expert opinion following the 'country's domestic conditions. Tables 3 and 4 represent the final criteria and factors obtained to achieve project success.

3.4. Machine Learning. A computer program is said to learn from experience E concerning some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, it improves with experience E [18–22]. Machine learning allows computer programs to identify and obtain data from the real world and implement many assignments based on the new information [19]. Machine learning of computer programming is to optimize the performance criteria using example data or past experience [20]. Machine learning is a discipline of computer science, the goal of which is to teach computers to learn with no explicit programming [21, 31, 32].

3.5. Use of Artificial Intelligence Tools in Project Success. In a research field, the use of artificial intelligence subsets in predicting project success has created a broad range of goals. To better understand this, they will be divided into groups of those attempting to predict project success and those attempting to identify critical success factors.

3.5.1. Identification of Critical Success Factors. These algorithms have been identified in the literature assessment to recognize critical success factors (CSF) as: (1) neural networks, (2) fuzzy cognitive maps (FCM), (3) genetic algorithms, and (4) the Bayesian model [22].

3.5.2. Determining Project Success. In addition, some articles have attempted to predict project success for the duration of the project life cycle in its initial stage or any other time of the project. These algorithms can be found for the prediction of project success as follows: (1) Bayesian model, (2) evolutionary fuzzy neural inference model (EFNIM), (3) neural networks, (4) machine learning with support, (5) genetic algorithm, (6) K-clustering, (7) bootstrap neural networks, and (8) adaptive neural networks [22].

3.6. Using Machine Learning in Project Success. Martínez and Fernández-Rodríguez [22] pointed out that artificial intelligence and machine learning 'methods' performance was better than traditional techniques regarding estimating the project performance due to their ability to deal with project uncertainty and today's complex environment effectively. Among the studied artificial intelligence algorithms, machine learning has the potential to improve conventional classification methods for use in construction significantly. Data mining and machine learning are promising methods for revealing invisible patterns in a large volume of data, which can be used for predicting future behaviors. The results obtained for project delay anticipation help managers classify risks related to the execution stages. Additionally, those results can contribute to the delays' detection and primary sources before their occurrence. They cannot minimize outcomes but can measure progress to success [23]. Machine learning algorithms work by learning from historical data in a way that easily complements expert opinion [24]. Over the past few decades, there have been significant advances in predictive modeling techniques and concepts of machine learning, statistics, and computer science that are valuable to researchers and organizational practitioners [25]. In a study, various machine learning methods were used and compared to predict the key performance indicator (KPI) of the project in critical project stages. Moreover, a framework was presented to measure and predict a set of qualitative KPIs by using various machine learning techniques [26]. Moreover, a machine learning method was used to generate a model that could

Table 2: The evolution of success criteria over different decades.

Success criteria	The 1960s	The 1970s	The 1980s	The 1990s	The 2000s	The 2010s
Project	—	—	—	Scope, type, complexity, size, and project life cycle	Type, scope, clear goals, and actual budgeting	Type, scope, clear goals, and budgeting
Project management	Scheduling feedback	Schedule monitoring, control, scheduling, and review	Scheduling, communications, cost estimation, funding, financial support, and reasonable needs	Feedback, communication, decision impact, and planning monitoring	Scheduling control, management actions, scheduling, control, decision-making, and communication	Scheduling control, control, decision-making, and control of all project management actions
Public management and organizational aspects	Senior management support	Public management support	Senior management support, public management efficiency, and organizational aspects	Organizational structure, safety and quality programs, and senior management support	Flexible management, change management, and organizational structure	Change management, organizational structure, and risk management
Procurement, purchase, and preparation	—	Resource allocation	—	Preparation and maintenance procedures	—	Precise control of resource allocation
Environment	—	—	—	Social, political, and technical	Economics, political, physical, social, technical relations of industries, education from past experiences, and organizational culture	Learning from past experiences, organizational culture, and environmental factors
Individuals	—	Project management	Customer profile, individual capabilities, project management, project team quality, and individual strength	Project management experience, commitment, competence, ability, authority, customer power, customer type, customer/consumer conflicts, team spirit, level of service, and contractor team components	Customer experience, size, quality expectations, continuity duration, team leader planning, organization, dynamics, control capabilities, customer approaches, stakeholder management, and contract flexibility	Customer experiences, stakeholder expectations, team leader planning, organization, control capabilities, stakeholder management, team spirit, team success, and business interests

predict the safety performance based on leading indicators regardless of the number or type of leading indicators available [27]. In another research, the goal was to find ways to increase executive efficiency and the use of novel project management technologies by integrating them with artificial intelligence technologies. To solve these problems, the causes of lack of success or unsuccessful management of project were assessed in the area of the extreme increase in project management information flow, the criteria of the effect of materials on project results were prioritized, and artificial intelligence was categorized in their use for project management. Therefore, artificial intelligence tools and technologies can effectively help the management of complex projects with large data flows [28]. The goal of predictive models developed by machine learning is to improve performance by increasing the prediction of KPIs. The project results can be improved if the predicted results are unfavorable and corrective measures are taken. Therefore, it will be difficult to evaluate model predictions. Accordingly, it can be learned that machine learning concepts are a good way to understand the performance and success of a project [29]. Project delay is one of the most important challenges of construction, which is attributed to the complexity of the sector and the interdependence of its inherently delayed risk sources. Machine learning is an ideal technique for dealing with such complex systems. This study aimed to identify and develop machine learning models to accurately analyze project delay risks and prediction by using objective data

Table 3: Final project success criteria.

Symbol	Project success criteria
C1	Completion of the project with the approved budget
C2	Completion on time
C3	Maximum achievement of safety indicators
C4	Compliance with quality standards
C5	Satisfaction of all stakeholders aulfilmentent of their demands (employer, consultants, contractors, employees and personnel, customer and users, and people)
C6	Alignment with the environment
C7	Gaining commercial and other benefits
C8	Alignment with organizational goals and strategies
C9	Minimal changes in organizational culture resulting from the project in the organization
C10	Increased level of knowledge in the organization
C11	Creating motivation for future projects
C12	Minimal impact of the project from environmental factors (political, economic, and cultural)
C13	Stability of management strategy
C14	Achieving specific project goals
C15	Minimal changes in project scope
C16	All participants' similar perceptions of project success

Table 4: Final project success factors.

Symbol	Final success factors
F1	Provision and allocation of financial resources
F2	Emphasis on goals (time, cost, and performance)
F3	Forming the right team (finding the right people, providing the necessary resources and motivating the overall understanding of the project)
F4	Teamwork (cooperation, confidence, and trust)
F5	Selection of suitable contractors (history, financial capacity, competence, and commitment)
F6	Selection of suitable consultants (history, financial capacity, competence, and commitment)
F7	Attracting workshop manpower
F8	Creating clear and logical goals
F9	Change management and readiness to accept changes in the system
F10	Delegation of authority by senior managers (giving sufficient authority)
F11	Support by senior managers (in times of crisis)
F12	Behavioral and professional skills of managers and engineering team
F13	Managers' attitudes based on the views of the private sector or the public sector
F14	Adequacy of related knowledge and experience in the employer organization
F15	Existence of executive history in organizations
F16	Existence of appropriate organizational structure at each stage
F17	Continuous, transparent, accurate, and fast communication
F18	Proper and timely rotation of information and correspondence
F19	Existence of appropriate reward and motivation systems
F20	Existence of appropriate educational structures in the project life cycle
F21	Transparency of project specifications (teacher and executive plans)
F22	Alignment with organizational strategies
F23	Clarity and speed in providing technical solutions
F24	Financing reference (national, provincial, and private)
F25	Providing quality materials, equipment, and machinery
F26	Existence of executive history of the application of new technologies
F27	Existence of experience in using the quality control system
F28	Inflation rate
F29	Familiarity with government laws and regulations and their observance (e.g., safety and environment)
F30	Familiarity with the geographical conditions and climate of the project
F31	Awareness of the project (needs, wants, activities, and acceptance criteria)
F32	Existence of planning process throughout the life of the project, scheduling, risk management, and resource planning
F33	Existence of a control system throughout the project life cycle (evaluation, comparison, providing accurate, and meaningful information)

sources. Accordingly, the delay risk factors and sources were identified first, and multivariate datasets of previous projects' time performance and sources of delayed risk were prepared. Afterward, the complexity and interdependence of the system were discovered through the analysis of exploratory data. Ultimately, the work presented here benefited from machine learning's power to facilitate evidence-based decision-making [30]. A machine learning approach can be presented to predict the project performance based on various criteria of entrepreneurial orientation and entrepreneurial attitude of individuals to analyze and predict project success [31]. A study proposed guidelines for applied machine learning (AML) for the construction industry. This study is a part of the development of a machine learning-based construction simulation tool, the goal of which is to use historical data for automation or facilitation of construction activities, such as opportunity selection, design optimization, construction estimation, and project execution in line with project success [32].

4. Discussion

This study can be divided into three main areas of project success, machine learning, and its use in project management. Therefore, the following results are summarized. The result of the first section showed that projects exist to achieve the strategic goals of their respective organizations. Notably, the importance of project results is related to achieving success and achieving the goals of relevant organizations as well as gaining the satisfaction of their stakeholders. Studies conducted on project success can be divided into two sections; research that seeks to assess the success of projects and research that is formed to predict project success. The first class of studies is often developed to more accurately understand the concept of success, determine the criteria for success and present solutions to evaluate the success of projects. The second class of studies is performed on project success to present a project success prediction model. Among the research proposed for future studies, new artificial intelligence methods, especially machine learning, are the newest and most widely used methods for predicting the project's future. Some of the advantages of this method include high accuracy, learning ability, the ability to adapt to conditions and uncertainties, the ability to self-assess, simplicity but at the same time high strength, and no need for heavy mathematical operations. According to the study's results, project managers must use novel techniques to predict the project performance and success due to the limitations of conventional approaches. Even though managers still need to evaluate the success of a project based on time, cost, and quality, it is crucial to identify factors that determine the project performance from the perspective of a person. In this respect, the current research proposed new criteria that affect the project performance. In addition, we identified the most effective project performance factors for the success of construction projects. For instance, the technical aspects of a building are of great importance and are incredibly suitable for forecasts. While external factors and technical aspects of a building are significant for the success of a project, human factors can have the most impact on the project performance. Our findings provided a new insight for researchers in the field of project management to understand the effect of project success factors that directly affect the project performance.

5. Conclusion

To sum up, all the notable findings and results of the present research can be summarized as follows:

(1) Given in the literature, success was identified as a multifaceted and complicated concept, and different people have different perceptions of it. This can be said because no consensus regarding the idea of success can be achieved among all stakeholders of a particular project.

(2) According to library studies and expert opinions and employing tools, including interviews and electronic questionnaires, we identified 16 and 33 criteria and factors for project success, respectively, while considering domestic conditions.

(3) Factors, including role, type, position, goals and stakeholders' approaches, and several other elements result in variations in the priorities and weights of each of those sixteen criteria amongst project stakeholders. Each stakeholder provides their definition of project success according to the importance and priority of standards related to the position and role of their organization in the project, which leads to multiple definitions of this term.

(4) Using machine learning tools and algorithms to connect project success factors and criteria and prediction can lead to many advantages, such as high accuracy, ease of use, and inference for decision-making.

According to the study's results, artificial intelligence tools, such as machine learning, are more accurate than conventional instruments. Nonetheless, they are still used as a complement to traditional tools. These tools can highly benefit project managers in project monitoring and control. Nevertheless, some of the evaluated models had weaknesses, demonstrating that project managers should still use allocation judgment and compare results with conventional tools before making the necessary adjustments. Best results when integrating AI tools with project-specific tools, such as CAPP, which allows real-time analysis, and PDRI, which allows you to evaluate how a project is defined in its early stages before a project starts, can allow us to provide solutions that project managers can use to prevent possible risks based on previous experiences.

Algorithmic solutions should be integrated in a way that project managers and their teams can sufficiently use them to improve project success by reducing possible risks before their occurrence and guiding the project toward achieving its goals. The current research contributed to construction studies by showing machine learning as a project performance evaluation method. The causes of delays and excessive cost increases are significant in the construction industry, while the goal is to optimize and increase productivity. Success or failure factors are described in detail that can be used in prediction using machine learning methods. Overall, such intelligent platforms affect the practical situation by addressing the need to convert multidimensional historical data of completed projects to the value of large corporations. Such a value enables construction companies to avoid evidence-based knowledge and data-backed decisions to prevent future construction failure. It can be concluded that machine learning concepts are a suitable method for understanding the project performance.

Thus, the suggestions below are recommended for future outlook:

(1) Proposing a model of success prediction by utilizing machine learning tools;
(2) Determining predictive models by recognizing the related success factors;
(3) Presenting a model for specific projects;
(4) Offering a model by simultaneous integration of evaluator models and success prediction models.

Data Availability

The data are available upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Research Article

Choice and Influence of Return Policy and Remanufacture in a Dual-Channel Supply Chain

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To investigate the choice of return strategy and its impact on a dual-channel supply chain, a game model is constructed to analyze the equilibrium outcomes of five scenarios: no returns allowed, refunds without returns, returns allowed but no return shipping insurance, returns allowed and return shipping insurance purchased by the manufacturer, and returns allowed and return shipping insurance purchased by the consumer. The study found that manufacturers offering refund policies generate more sales in the direct online channel, while retailers choose to reduce the retail price of their products. It is important to note that price reductions by retailers have a very limited effect and do not lead to an increase in sales in the retail channel. Manufacturers offering refund policies will inevitably infringe on retailers' profits, and the variability of manufacturers' profits depends on the residual value of returned products. Manufacturers should decide whether to offer a refund policy in online direct sales channels based on the residual value of the returned product; otherwise, the action would be detrimental to themselves. The price of direct online sales is the same whether the manufacturer buys the return shipping insurance or the consumer buys the return shipping insurance, but when the return shipping insurance is bought by the consumer, sales are higher in the direct online channel and lower in the retail channel. When the return shipping cost reimbursement received after purchasing return shipping insurance is low, it should be purchased by the manufacturer, and when the return shipping cost reimbursement received after purchasing return shipping insurance is high, it will be better for the consumer to purchase return shipping insurance.

1. Introduction

With the continuous development of information technology and e-commerce, online shopping has become one of the consumers' main shopping methods. Statistics show that as of June 2021, the number of online shopping users in China reached 812 million [1]. This shows that the rapid growth of e-commerce is changing the traditional sales model and will have a huge impact on the physical retail sector. While enjoying the convenience of online shopping, it is also important to see the problems that exist. Compared to physical retail stores, online shopping is more prone to returns due to the lack of real-life experience. For this reason, the major online shopping platforms offer a variety of different return services to consumers. For merchants, there is a choice of whether to allow consumers to return goods and whether to provide return shipping insurance. It is optional for the consumer to choose whether to purchase the product and whether to take out return shipping insurance. While merchants' return policies undoubtedly enhance consumer satisfaction with online shopping, these policies can also lead to increased speculative spending by consumers and invariably increase the cost to merchants. To reduce the additional costs caused by returns, merchants will remanufacture returned products and resell them, thus making the subject of return shipping insurance and the remanufacturing of returned products a point of contention. Therefore, manufacturers selling products in online channels will compete with brick-and-mortar retailers.

The innovations of this research and the main objectives are as follows:

(1) Whether manufacturers should provide return services and return shipping insurance in the face of return claims from consumers in online channels.
(2) Which return policy should the manufacturers provide?
(3) Whether they should remanufacture returned products are the issues that this paper will study.

2. Literature Review

There are two main areas of literature relevant to the study of this paper: one is research related to the issue of returns, and the other is research on the issue of remanufacturing. Regarding research on returns, Oghazi et al. [2] showed that a lenient return policy can increase customer trust and thus customer willingness to buy. Jeng [3] studied the impact of return policies on consumer purchase intentions in terms of brand awareness. Yang and Li [4] showed that under different sales models, the money-back guarantee always leads to lower demand for the product and has an impact on optimal pricing. Further research by Jin et al. [5] found that money-back guarantees can have an impact on the pricing strategies of both sides of the brand differentiation supply chain but that manufacturers and online retailers are able to make more profit when certain conditions are met. Huang et al. [6] studied a secondary supply chain yield decision problem considering consumer returns, analyzing the impact of offering a money-back guarantee on the equilibrium outcome and the threshold for opening a direct sales channel. The study found that the equilibrium outcome of a manufacturer offering a money-back guarantee compared to a retailer offering a money-back guarantee was consistent, except for the higher wholesale price. Zhao et al. [7] study the impact of return guarantees on merchants' pricing and revenue from the perspective of consumers' opportunistic behavior. Hu et al. [8] studied the pricing strategies of dual-channel retailers when offering customers a return strategy and showed that proper return policies not only improve the flexibility of business operations but also enhance consumers' sense of security. Li et al. [9] studied the strategic effects of return strategies in a dual-channel supply chain and showed that customer return rates were the main factor influencing refund strategies. J. Chen and B. Chen [10] consider the impact of return policy tolerance on retailer pricing when there are multiple retailers coexisting in the market. Zhao and Hu [11] investigated the issue of return shipping cost coverage and showed that to maximize profits, online retailers should choose strategies that are appropriate to the characteristics of the proportion of defect-free returns of goods. Nie et al. [12] studied the impact of money-back guarantees on the opening of direct sales channels by manufacturers and the respective money-back guarantee strategies and market equilibrium of manufacturers and retailers under a dual-channel model. Huang et al. [13] studied the impact of money-back guarantees on product quality and service in the supply chain. Zhang and Jin [14] investigated the issue of optimal pricing for e-retailers and contract design for manufacturers under a money-back guarantee. Wu et al. [15] showed that factors such as product quality, market demand, and price have an impact on the amount of product returns and the manufacturer's optimal decision. Radhi and Zhang [16] studied the impact of customer preferences and customer recall rates on dual-channel pricing. The above literature has examined the impact of return guarantees and return policies on consumers and firms but has not addressed the issue of how returned products are subsequently handled.

The National Development and Reform Commission issued the "opinions on promoting the development of remanufacturing industry" and mentioned that accelerating the development of remanufacturing industry is an effective way to promote the development of manufacturing and modern service industry; remanufacturing is the organic combination of manufacturing and repair, recycling and utilization, and production and circulation. The study of remanufacturing issues is of great significance in enhancing the efficiency of enterprises and promoting the development of a circular economy. Lotfi et al. [17] proposed a resilient and sustainable supply chain network design considering renewable energy sources. Lotfi et al. [18] proposed a medical waste chain network design for medical waste generated during COVID-19 treatment. Waste segregation was proposed to locate the wastes to reduce them, recycle them, and send them to the waste purchase contractor. Lotfi et al. [19] proposed a viable closed-loop supply chain network that considers resiliency, sustainability, and agility. In order to solve the problem, they suggested a hybrid robust stochastic optimization by minimizing the weighted expected, maximum, and entropic value at risk (EVaR) of the cost function for this problem. Li et al. [20] studied the time value of returned products in the reverse supply chain. By analyzing retailers' optimal return prices, Li et al. [21] found that manufacturers are able to reconcile retailers' optimal return prices through buybacks and remanufacturing of returned products to achieve supply chain coordination. Radhi and Zhang [22] studied the impact of resalable returns on order volume across channels. Xing et al. [23] studied the impact of remanufacturing links on the cost of dual-source inventory in a closed-loop supply chain. Xia et al. [24] studied the impact of changes in return logistics costs on price volatility and supply chain system efficiency for remanufacturers and retailers. Hu et al. [25] analyzed the impact of return rates, remanufacturing ratios, and customer sensitivity factors to retail and return prices on return prices and profits and gave corresponding return price pricing strategies. Xu et al. [26] showed that the choice of a manufacturer's remanufacturing strategy depends on the production cost of the remanufactured product, and when the cost of the remanufactured product is low, the implementation of a remanufacturing strategy can increase the profits of both the manufacturer and the retailer, allowing the whole supply chain system to be optimized. Chen and Dong [27] analyzed the impact of own funds investment in emission reduction and carbon emission thresholds on remanufacturing decisions. Lin et al. [28] analyzed the impact of retailers on remanufacturing from the perspective of their complicity with remanufacturers. Cao and Zhu [29] analyzed the impact of firms' investment efficiency on the equilibrium decision to recycle and remanufacture. Xia and Zhu [30] investigated the impact of remanufacturing design on manufacturing/remanufacturing under authorized remanufacturing. Ullah et al. [31] investigated the optimal remanufacturing strategy for a single-/multi-retailer closed-loop supply chain under stochastic demand and return rates. Shekarian et al. [32] studied the impact of carbon emissions and remanufacturing on the dual channel of forward and reverse logistics. Bansal et al. [33] studied the role of remanufacturing in product development and associated profit estimation. In the above literature, scholars have focused on the issue of remanufacturing but have not considered the issue of the remanufacturing of returned products and its impact on supply chain return strategies.

In summary, the existing literature focuses on the impact of money-back guarantees on consumers and businesses, and research on the handling of returned products has focused on the impact on inventory costs and product prices, with little research on the impact of remanufactured returned products on supply chain members' return strategies under competitive channels. Based on the above analysis, this paper examines the choice of a manufacturer's return strategy based on a two-tier supply chain consisting of a single manufacturer and a single retailer, where the manufacturer sells its products both through traditional retailers and directly through online channels, to provide theoretical guidance on the choice of a manufacturer's remanufacturing pricing and return strategy. We selected some studies related to our work as a comparison to clearly illustrate the similarities and differences between the relevant literature and this paper in Table 1.

3. Problem Description and Notations

Consider a two-tier supply chain consisting of a single manufacturer and a single retailer, with the manufacturer selling products both through traditional retail channels and through direct online sales channels. The manufacturer is the dominant player in the supply chain, with the retailer as the follower. The manufacturer decides on the wholesale price of the product, the direct internet price, and the return strategy; the retailer decides on the retail price of the product. The manufacturer sells the product to the end consumer at the direct network price p_d and the retailer at the retail price p_r, and the production cost per unit of product is c. According to the Hotelling model, the total market is defined as 1, consumers are uniformly distributed in a unit linear market, and consumers value the product as v.

As consumers cannot physically experience the product when shopping online, it is reasonable to assume that if the product purchased online does not meet the consumer's expectations, the consumer will request a refund from the retailer. In commercial practice, merchants allow consumers to simply request a refund without returning the product if the product cannot be resold after the return or if the product is of low value. If the product itself has no quality problems or is repaired and does not affect secondary sales, the consumer will have to pay the return shipping costs s to return the product. Some merchants choose to spend t on return shipping insurance to reduce the negative impact of return shipping costs on consumers' willingness to buy. If the merchant does not offer return shipping insurance, consumers can also choose to purchase their own return shipping insurance at a cost of t to reduce the risk of returning the goods. When merchants give away return shipping insurance or consumers buy their return shipping insurance, consumers will receive a certain amount of compensation for return shipping costs once the goods are returned from online shopping r. Products returned by consumers are sorted by the manufacturer according to the residual value φ, and those of them without quality problems are put back on the market, while those of them with quality problems are remanufactured and resale. The cost used to remanufacture the returned product is c_i, and the price to resale the returned product after it has been remanufactured is ρ. Based on whether the manufacturer offers consumers a return policy and complimentary return shipping insurance in the online direct sales channel, whether the consumer purchases the product, and whether the consumer purchases return shipping insurance, the following five scenarios are considered:

(1) No returns allowed (*NN*): The manufacturer will not accept returns from consumers who are not satisfied with the products they receive after purchasing them through direct online sales channels.

(2) Refunds without returns (*RN*): Consumers who are not satisfied with the products they receive after purchasing them through direct online sales channels can apply for a refund without having to return the products.

(3) Return allowed but no return shipping insurance (*MN*): The manufacturer offers a return policy that allows the consumer to return unsatisfactory products, but the manufacturer does not give return shipping insurance and the consumer does not purchase return shipping insurance. In this case, the manufacturer allows the consumer to return the product, but the return shipping costs incurred are borne by the consumer.

(4) Allowing returns and having the manufacturer purchase return shipping insurance (*MR*): The manufacturer allows the consumer to return the product and gives the consumer return shipping insurance. This practice by the manufacturer can alleviate consumers' concerns and increase their willingness to buy.

(5) Allowed returns with return shipping insurance purchased by the consumer (*MC*): The manufacturer allows the consumer to return the product, but the return shipping insurance is purchased by the consumer. In this case, the consumer purchases his or her own return shipping insurance, which will reimburse him or her for the return shipping costs if

Table 1: Comparison among recent relevant studies.

Literature	Dual-channel	Return policy	Buyer's return insurance	Seller's return insurance	Remanufacturing	Remanufacturing of returned products	Impact on return strategies
Oghazi et al. [2]	—	✓	—	—	—	—	—
Hu et al. [8]	✓	✓	—	—	—	—	—
Li et al. [9]	✓	✓	—	✓	—	—	—
Zhao and Hu [11]	—	✓	✓	✓	—	—	—
Nie et al. [12]	✓	✓	—	—	—	—	—
Radhi and Zhang [16]	✓	✓	—	—	—	—	—
Radhi and Zhang [22]	✓	✓	—	—	—	✓	—
Xia et al. [24]	—	—	—	—	—	✓	—
Shekarian et al. [32]	✓	—	—	—	—	✓	—
This paper	✓	✓	✓	✓	✓	✓	✓

the consumer is not satisfied with the product after receiving it online.

To define the research question and to facilitate the construction of the subsequent model, the following research assumptions are made:

(1) In the process of the game, the manufacturer and the retailer are information symmetric, and they are risk neutral (similar to literature [34]).

(2) Whether a consumer purchases a product depends on the consumer's willingness to pay and utility. To illustrate the rate of consumer demand for a product, the total market is defined as 1.

(3) It is assumed that the consumer purchases only 1 unit of the product during the sales cycle and does not consider the case where the consumer purchases more than one product.

(4) The return rate of products purchased by consumers at offline retailers is low because consumers can experience the products firsthand when they purchase them at offline retailers. To simplify and highlight the research questions, this paper only considers returns that occur when consumers purchase products in online channels.

(5) Consumers are unable to experience the products they purchase online, and as a result, it is the case that online purchases do not meet expectations. Assume that the probability that a consumer's online purchase meets his or her expectations is $\theta (0 < \theta < 1)$.

(6) When a manufacturer offers a return policy in the online channel, if a consumer's online purchase does not meet expectations, the consumer will return the product and receive a full refund.

(7) In the process of the game, the manufacturer and the retailer are information symmetric, and they are risk neutral.

The notations used in this paper are described in Table 2.

3.1. No Returns Allowed. In cases where returns are not allowed (indicated by the superscript *NN*), the manufacturer will not accept returns if the consumer is not satisfied with the product received after purchasing it through the direct online sales channel. In this case, if the consumer's online purchase meets his or her expectations, then the utility gained by the consumer is $v - p_d$. If a consumer's online purchase does not meet expectations and since the manufacturer does not allow returns, the consumer receives a utility of $0 - p_d$. Therefore, in a scenario where returns are not allowed, the expected utility obtained by a consumer purchasing a product from a direct online sales channel is

$$U_d^{NN} = \theta(v - p_d) + (1 - \theta)(0 - p_d). \tag{1}$$

The expected utility received by the consumer from the retailer for purchasing the product is:

$$U_r^{NN} = v - p_r. \tag{2}$$

Consumers make purchase decisions based on the magnitude of expected utility, which is based on max $(U_d, U_r, 0)$. Defining the total market as 1, consumers' valuation of product v is heterogeneous, and v follows a uniform distribution of $[0, 1]$. Clearly, there are three critical states of consumer choice:

(1) $\theta(v - p_d) + (1 - \theta)(0 - p_d) = 0$, the consumer valuation at this point is defined as $V_d = p_d/\theta$

(2) $v - p_r = 0$, the consumer valuation at this point is defined as $V_r = p_r$

(3) $\theta(v - p_r) + (1 - \theta)(0 - p_d) = v - p_r$, the consumer valuation at this point is defined as $V_{dr} = p_r - p_d/1 - \theta$ Then the demand for both channels can be discussed in the following three scenarios:

(1) When $V_r \geq V_d$ and $V_{dr} \leq 1$, that is, $p_d/\theta \leq p_r \leq 1 + p_d - \theta$. At this point, both channels

Table 2: Summary of notations.

Parameter	Definition
p_d	Manufacturer network channel direct sales prices
p_r	Retail price
w	Wholesale price
c	Unit production cost
v	Consumer valuation of products
θ	Probability that a consumer's online purchase will meet his or her expectations
φ	Returned product salvage rate
ρ	Price of returned products remanufactured for resale
c_i	Returned product remanufacturing costs
s	Return shipping costs
r	Reimbursement of return shipping costs following the purchase of return shipping insurance
t	Cost of purchasing return shipping insurance

have consumers buying the product, and the demand functions for the two channels are $D_d^{NN} = p_r - p_d/1 - \theta - p_d/\theta$ and $D_r^{NN} = 1 - p_r - p_d/1 - \theta$, respectively.

(2) When $V_r \geq V_d$ and $V_{\text{dr}} \geq 1$, then $p_r \geq 1 + p_d - \theta$. At this point, the consumer's utility from purchasing the product from the direct online channel is greater than that from the retail channel, and the demand functions for the two channels are $D_d^{NN} = 1 - p_d/\theta, D_r^{NN} = 0$.

(3) When $V_r \leq V_d$, that is, $p_r \leq p_d/\theta$. At this point, the consumer obtains more utility from purchasing the product from the retail channel, and the demand functions for the two channels are $D_d^{NN} = 0, D_r^{NN} = 1 - p_r$, respectively.

As this paper examines the situation where both channels of demand exist simultaneously, the paper will be followed up with an analysis based on the following demand function:

$$\begin{aligned} D_d^{NN} &= \frac{p_r - p_d}{1-\theta} - \frac{p_d}{\theta}, \\ D_r^{NN} &= 1 - \frac{p_r - p_d}{1-\theta}. \end{aligned} \tag{3}$$

Based on the above demand function, the profit functions of the manufacturer and the retailer are further obtained as follows:

$$\begin{aligned} \pi_d^{NN} &= (w-c)D_r^{NN} + (p_d - c)D_d^{NN}, \\ \pi_r^{NN} &= (p_r - w)D_r^{NN}. \end{aligned} \tag{4}$$

Proposition 1. *The selling price, sales volume, and profit of the retailer and manufacturer in the no return scenario are as follows:* $p_r^{NN} = 3 + 2c - \theta/4$ *and* $p_d^{NN} = \theta + c/2$, $D_r^{NN} = 1/4$ *and* $D_d^{NN} = \theta - 2c/4\theta$, *and* $\pi_r^{NN} = 1 - \theta/16$ *and* $\pi_d^{NN} = 2c^2 - 4\theta c + \theta^2 + \theta/8\theta$.

The Proof of Proposition 1 and subsequent propositions and corollaries is given in the Appendix. Corollary 1 can be further obtained from Proposition 1.

Corollary 1. *The impact of the probability* θ *of online goods meeting expectations in the no return scenario on the sales price, sales volume, and profit of the retailer and manufacturer, respectively, is as follows:* $\partial p_r^{NN}/\partial\theta < 0$ *and* $\partial p_d^{NN}/\partial\theta > 0$, $\partial D_r^{NN}/\partial\theta = 0$ *and* $\partial D_d^{NN}/\partial\theta > 0$, *and* $\partial\pi_r^{NN}/\partial\theta < 0$ *and* $\partial\pi_d^{NN}/\partial\theta > 0$.

Corollary 1 suggests that in a no-return scenario, the greater the probability that a consumer's purchase from an online direct marketing channel will meet his or her expectations, the lower the risk of the consumer's online purchase, and the greater the consumer's willingness to purchase the product from the online direct marketing channel, and the corresponding increase in sales volume of the online direct marketing channel. At the same time, manufacturers will set higher prices for direct online sales, and the combination of these two effects leads to higher profits for manufacturers. As the probability of consumers purchasing products from online direct sales channels increases to meet their expectations, retailers will choose to reduce the retail price of their products to attract consumers to continue to purchase products from the retail channel; however, the effect of price reduction by retailers is very limited and does not lead to an increase in sales volume but only to maintain the original sales volume. As a result of the reduction in the retail price, the retailer's profitability ultimately decreases.

3.2. Refunds without Returns. In the case of a refund without returns (indicated by the superscript *RN*), the manufacturer allows the consumer to receive a refund and does not have to return the product if the product does not meet expectations and the returned product cannot be resold or is of low value. In this case, if the consumer's online purchase meets his or her expectations, then the utility gained by the consumer is $v - p_d$; if a consumer's online purchase does not meet expectations, the consumer receives a utility of φv, where φ is the residual value of the returned product, as the merchant refunds the full amount and does not require a return:

$$U_d^{RN} = \theta(v - p_d) + (1-\theta)\varphi v. \tag{5}$$

The utility gained by the consumer from purchasing the product at the retailer is

$$U_r^{RN} = \nu - p_r. \tag{6}$$

In line with the previous section, only the case where both channels of demand exist simultaneously is considered, at which point the demand functions for the direct online channel and the retail channel are

$$D_d^{RN} = \frac{p_r - \theta p_d}{(1-\theta)(1-\varphi)} - \frac{\theta p_d}{\theta + (1-\theta)\varphi},$$
$$D_r^{RN} = 1 - \frac{p_r - \theta p_d}{(1-\theta)(1-\varphi)}. \tag{7}$$

Based on the above demand function, the profit functions of the manufacturer and the retailer are further obtained as follows:

$$\pi_d^{RN} = (w-c)D_r^{RN} + \theta(p_d - c)D_d^{RN} - (1-\theta)cD_d^{RN},$$
$$\pi_r^{RN} = (p_r - w)D_r^{RN}. \tag{8}$$

Proposition 2. *The selling price, sales volume, and profit of the retailer and manufacturer in the refund-no-return scenario are as follows:* $p_r^{RN} = (\theta-1)\varphi + 2c + 3 - \theta/4$ *and* $p_d^{RN} = \theta + c + \varphi - \theta\varphi/2\theta$, $D_r^{RN} = 1/4$ *and* $D_d^{RN} = (\theta-1)\varphi + 2c - \theta/(4\theta-4)\varphi - 4\theta$, *and* $\pi_r^{RN} = (\theta-1)(\varphi-1)/16$ *and* $\pi_d^{RN} = -(\theta-1)^2\varphi^2 - (4c - 2\theta - 1)(\theta-1)\ \ \varphi - \theta^2 + (4c-1)\theta - 2c^2/(8\theta-8)\varphi - 8\theta$.

Proposition 2 leads to Corollary 2, which further analyses the impact of the probability θ of online goods meeting expectations on the sales price, sales volume, and profits of retailers and manufacturers.

Corollary 2. *The impact of the probability* $\partial p_d^{RN}/\partial\theta < 0$ *of an online purchase meeting expectations in the refund-no-return scenario on the sales price, sales volume, and profits of retailers and manufacturers is as follows:* $\partial p_r^{RN}/\partial\theta < 0$ *and* $\partial p_d^{RN}/\partial\theta < 0$, $\partial D_r^{RN}/\partial\theta = 0$ *and* $\partial D_d^{RN}/\partial\theta > 0$, *and* $\partial\pi_r^{RN}/\partial\theta < 0$ *and* $\partial\pi_d^{RN}/\partial\theta > 0$.

Corollary 2 suggests that in a refund-no-return scenario, as the probability that consumers will meet their expectations by purchasing products from online direct sales channels increases, both manufacturers and retailers will reduce their selling prices to attract more consumers. At this time, sales volume in the direct online sales channel will increase due to the increased willingness of consumers to purchase products in the direct online sales channel and the lower prices of direct online sales. Although the price of direct internet sales is reduced, the act of reducing the price can lead to a rapid increase in sales volume, which ultimately leads to higher profits for the manufacturer. However, the effect of the retailers' price cuts was very limited, and only the original sales volume was maintained. For retailers, the reduction in retail prices while sales volumes remain the same ultimately leads to a reduction in retailer profits.

3.3. Returns Allowed but No Return Shipping Insurance. In the case of returns allowed but no return shipping insurance (indicated by the superscript *MN*), when a consumer's online purchase does not meet expectations, the manufacturer allows the consumer to return the goods but does not provide return shipping insurance, and the consumer is responsible for the return shipping costs. In this case, if the consumer's online purchase meets his or her expectations, then the utility gained by the consumer is $\nu - p_d$; if a consumer's online purchase does not meet expectations, the utility gained by the consumer at this point is $0 - s$, where s is the return shipping cost incurred by the consumer in returning the product. Therefore, in a scenario where the manufacturer allows returns but does not provide return shipping insurance, the expected utility obtained by the consumer from purchasing the product in the direct online channel is

$$U_d^{MN} = \theta(\nu - p_d) + (1-\theta)(0 - s). \tag{9}$$

The utility gained by the consumer from purchasing the product in the retail channel is

$$U_r^{MN} = \nu - p_r. \tag{10}$$

In line with the previous section, only the case where both channels of demand exist simultaneously is considered, at which point the demand functions for the direct online channel and the retail channel are

$$D_d^{MN} = \frac{p_r - \theta p_d - (1-\theta)s}{1-\theta} - \frac{\theta p_d + (1-\theta)s}{\theta},$$
$$D_r^{MN} = 1 - \frac{p_r - \theta p_d - (1-\theta)s}{1-\theta}. \tag{11}$$

In this case, the manufacturer will remanufacture and resell the returned product after evaluation, at which point the profit functions of the retailer and manufacturer are

$$\pi_r^{MN} = (p_r - w)D_r^{MN},$$
$$\pi_d^{MN} = (w-c)D_r^{MN} + \theta(p_d - c)D_d^{MN} + (1-\theta)(\rho - c - c_i)D_d^{MN}. \tag{12}$$

Proposition 3. *The selling price, sales volume, and profit for the retailer and manufacturer in the scenario where returns are allowed but there is no return shipping insurance are as follows:* $p_r^{MN} = \rho\theta - c_i\theta - s\theta - \rho + 2c + c_i + s - \theta + 3/4$ *and* $p_d^{MN} = \rho\theta - c_i\theta + s\theta - \rho + c + c_i - s + \theta/2\theta$, $D_r^{MN} = (1-\theta)(\rho - s - c_i - 1)/4\theta - 4$ *and* $D_d^{MN} = -(\rho - s - \ c_i - 1)\theta - 2\rho + 2c + 2c_i + 2s/4\theta$, *and* $\pi_r^{MN} = -(\theta-1)^2\ \ (\rho - s - c_i - 1)^2/16(\theta-1)$ *and* $\pi_d^{MN} = (\rho - s - c_i - 1)^2\theta^2 - (3\rho - 4c - 3s - 3c_i + 1)(\rho - s - c_i - 1)\theta + 2(\rho - c - s - c_i)^2/8\theta$.

Proposition 3 leads to Corollary 3, which further analyses the impact of the probability θ of online goods meeting expectations on the sales price, sales volume, and profits of retailers and manufacturers.

Corollary 3. *The probability of an online purchase meeting expectations in a scenario where returns are allowed but there is no return shipping insurance the impact of* θ *on the sales price, sales volume, and profits of retailers and manufacturers is as follows:* $\partial p_r^{MN}/\partial\theta < 0$ *and* $\partial p_d^{MN}/\partial\theta > 0$, $\partial D_r^{MN}/\partial\theta = 0$ *and* $\partial D_d^{MN}/\partial\theta > 0$, *and* $\partial\pi_r^{MN}/\partial\theta < 0$ *and* $\partial\pi_d^{MN}/\partial\theta > 0$.

Corollary 3 suggests that in a scenario where returns are allowed but there is no return shipping insurance, as the probability that consumers will meet their expectations by purchasing products from online direct sales channels increases, manufacturers will set higher online direct sales prices, while retailers will choose to reduce the retail price of their products to attract consumers to continue purchasing products from retail channels. As manufacturers offer consumers a return policy in the direct online sales channel, the risk of purchasing products from the direct online sales channel is reduced, and consumers' willingness to purchase products in the direct online sales channel increases; therefore, sales in the direct online sales channel will increase. The combination of the two effects leads to higher profits for manufacturers, as both online direct sales prices and sales volumes in the online direct sales channel are on the rise. However, the effect of price reductions by retailers is very limited and does not lead to an increase in sales but only to the maintenance of the same sales volume. As a result of lower retail prices, this ultimately leads to lower profits for retailers.

Next, the impact of the cost of remanufacturing returned products c_i on the selling prices, sales volumes, and profits of retailers and manufacturers is further analyzed.

Corollary 4. *The impact of the cost of remanufacturing returned products $\partial D_r^{MN}/\partial c_i > 0$ on the selling prices, sales volumes, and profits of retailers and manufacturers in a scenario where returns are allowed but there is no return freight insurance is as follows: $\partial p_r^{MN}/\partial c_i > 0$ and $\partial p_d^{MN}/\partial c_i > 0$, $\partial D_r^{MN}/\partial c_i > 0$ and $\partial D_d^{MN}/\partial c_i < 0$, and $\partial \pi_r^{MN}/\partial c_i > 0$ and $\partial \pi_d^{MN}/\partial c_i > 0$.*

Corollary 4 suggests that in a scenario where returns are allowed but there is no return shipping insurance, as the cost of remanufacturing the returned product rises, the manufacturer will set a higher direct internet sales price to cover its remanufacturing costs. As the price of direct online sales increases, sales volume in the direct online sales channel will consequently decrease, and more consumers will choose to buy products in the retail channel, with retailers taking the opportunity to increase the retail price of their products to make more profit. Due to the higher prices set by the manufacturer for direct online sales, the volume of sales in the direct online sales channel is declining, but it is not causing a decline in the manufacturer's profit.

3.4. Returns Are Permitted and Are Covered by the Manufacturer's Return Shipping Insurance. Where returns are permitted and return shipping insurance is taken out by the manufacturer (indicated by the superscript *MR*), when a consumer's online purchase does not meet expectations, the manufacturer allows the consumer to return the product and provides return shipping insurance, with the insurance company reimbursing the consumer for the cost of return shipping r. In this case, if the consumer's online purchase meets his or her expectations, then the utility gained by the consumer is $v - p_d$; if the consumer's online purchase does not meet expectations, the utility gained by the consumer at this point is $r - s$. Therefore, in a situation where the manufacturer allows returns and provides return shipping insurance, the expected utility gained by a consumer purchasing a product in a direct online sales channel is

$$U_d^{MR} = \theta(v - p_d) + (1 - \theta)(r - s). \quad (13)$$

The utility gained by the consumer from purchasing the product in the retail channel is

$$U_r^{MR} = v - p_r. \quad (14)$$

Consistent with the previous section, consider only the case where demand exists for both channels when the demand functions for the direct online channel and the retail channel are

$$D_d^{MR} = \frac{p_r - \theta p_d + (1 - \theta)(r - s)}{1 - \theta} - \frac{\theta p_d - (1 - \theta)(r - s)}{\theta},$$
$$D_r^{MR} = 1 - \frac{p_r - \theta p_d + (1 - \theta)(r - s)}{1 - \theta}. \quad (15)$$

In this case, the manufacturer will remanufacture and resell the returned product after evaluation, where the profit functions of the retailer and manufacturer are

$$\pi_r^{MR} = (p_r - w)D_r^{MR},$$
$$\pi_d^{MR} = (w - c)D_r^{MR} + \theta(p_d - c)D_d^{MR} + (1 - \theta)(\rho - c - c_i)D_d^{MR} - tD_d^{MR}. \quad (16)$$

Proposition 4. *The selling price, sales volume, and profit of the retailer and manufacturer in the case where returns are allowed and the manufacturer buys return shipping insurance are $p_r^{MR} = M\theta - N + c + t + 3/4$ and $p_d^{MR} = (M + 2)\theta - N + 2r - 2s + t/2\theta$, $D_r^{MR} = M - t - M\theta/4\theta - 4$ and $D_d^{MR} = -M\theta^2 + (3M - 2c - t + 2)\theta - 2N + 2t/4\theta(\theta - 1)$, and $\pi_r^{MR} = -(M\theta - M + t)^2/16\theta - 16$ and $\pi_d^{MR} = F + (E + z_1 c_i + z_2\rho + z_3 r + z_4 s + z_6)\theta/8\theta(\theta - 1)$, where $M = \rho + r - s - c_i - 1$, $N = \rho - c + r - s - c_i$, $F = M^2\theta^3 - 4M(N + t/2)\theta^2 - 2(N + t)^2$, $z_1 = -10\rho + 8c - 10r + 10s + 6t + 2$, $z_2 = -8c + 10r - 10s - 6t - 2$, $z_3 = -8c - 10s - 6t - 2$, $z_4 = 8c + 6t + 2$, $z_5 = -4t + 4$, $z_6 = t^2 + 2t - 1$, and $E = 5c_i^2 + 5\rho^2 + 5r^2 + 5s^2 + 2c^2 + z_5 c$.*

Proposition 4 leads to Corollary 5, which further analyses the impact of the probability θ of an online purchase meeting expectations on the sales price, sales volume, and profit of the retailer and manufacturer in a scenario where returns are allowed and the manufacturer purchases return shipping insurance.

Corollary 5. *The impact of the probability of an online purchase meeting expectations on the retailer's and manufacturer's sales price, sales volume, and profit in a scenario where returns are allowed and the manufacturer purchases return shipping insurance is as follows: $\partial p_r^{MR}/\partial\theta < 0$ and $\partial p_d^{MR}/\partial\theta > 0$, $\partial D_r^{MR}/\partial\theta > 0$ and $\partial D_d^{MR}/\partial\theta > 0$, and $\partial \pi_r^{MR}/\partial\theta < 0$ and $\partial \pi_d^{MR}/\partial\theta > 0$.*

Corollary 5 suggests that in a scenario where returns are allowed and the manufacturer purchases return shipping insurance, as the probability that consumers will meet their expectations by purchasing products from the direct online channel increases, the manufacturer will set a higher direct online price, and the retailer will choose to reduce the retail price of the product to entice consumers to continue purchasing the product from the retail channel. As manufacturers offer consumers a return policy in the direct online sales channel, the risk of purchasing products from the direct online sales channel is reduced, and consumers' willingness to purchase products in the direct online sales channel increases; therefore, sales in the direct online sales channel will increase. The combination of the two effects leads to higher profits for manufacturers, as both online direct sales prices and sales volumes in the online direct sales channel are on the rise. Unlike the previous three scenarios (where the retailer does not increase sales by reducing prices), in this scenario, the retailer can increase sales by reducing prices. Although sales volumes increased in the retail channel, it was difficult to recover from the decline in profits.

The impact of the cost of remanufacturing returned products c_i on retailers' and manufacturers' selling prices, sales volumes, and profits is then further analyzed, leading to Corollary 6.

Corollary 6. *The impact of the cost of remanufacturing the returned product $\partial D_d^{MR}/\partial c_i < 0$ on the selling price, sales volume, and profit of the retailer and manufacturer in a scenario where returns are allowed and the manufacturer purchases return shipping insurance is as follows: $\partial p_r^{MR}/\partial c_i > 0$ and $\partial p_d^{MR}/\partial c_i > 0$, $\partial D_r^{MR}/\partial c_i > 0$ and $\partial D_d^{MR}/\partial c_i > 0$, and $\partial \pi_r^{MR}/\partial c_i > 0$ and $\partial \pi_d^{MR}/\partial c_i < 0$.*

Corollary 6 suggests that in a scenario where returns are allowed and the manufacturer purchases return shipping insurance, as the cost of remanufacturing the returned product rises, the manufacturer will set a higher direct internet sales price to cover its remanufacturing costs. As a result of the increase in online direct sales prices, the sales volume in the online direct sales channel will consequently decrease; more consumers will choose to buy the products in the retail channel; and retailers will take the opportunity to increase the retail price of the products to gain more profit. As manufacturers set higher prices for direct online sales, sales volumes in the direct online sales channel fall sharply, ultimately leading to lower profits for manufacturers.

Next, the impact of the cost of purchasing return shipping insurance t and the return shipping reimbursement r received after purchasing return shipping insurance on retailers' and manufacturers' sales prices, sales volumes, and profits is analyzed, leading to Corollary 7.

Corollary 7. *The effect of parameters t and r on the selling price, sales volume, and profit of the retailer and manufacturer in the case where returns are allowed and the manufacturer purchases return shipping insurance is as follows: (1) $\partial p_r^{MR}/\partial t > 0$ and $\partial p_d^{MR}/\partial t > 0$, $\partial D_r^{MR}/\partial t > 0$ and $\partial D_d^{MR}/\partial t < 0$, and $\partial \pi_r^{MR}/\partial t > 0$ and $\partial \pi_d^{MR}/\partial t < 0$. (2) $\partial p_r^{MR}/\partial r < 0$ and $\partial p_d^{MR}/\partial r > 0$, $\partial D_r^{MR}/\partial r < 0$ and $\partial D_d^{MR}/\partial r > 0$, and $\partial \pi_r^{MR}/\partial r < 0$ and $\partial \pi_d^{MR}/\partial r > 0$.*

Corollary 7 suggests that the higher the reimbursement of return shipping costs provided by return shipping insurance, the lower the risk to consumers of purchasing products in online direct sales channels, where returns are allowed and return shipping insurance is purchased by the manufacturer. Consumers' willingness to buy products in the direct online sales channel increases, and therefore, the sales volume in the direct online sales channel will increase. Manufacturers offering return shipping insurance to consumers make consumers more willing to buy products in online direct sales channels, so manufacturers can set higher online direct sales prices to make more profit. With the increase in return shipping reimbursement, consumers will be more willing to purchase products in the online direct sales channel, and retailers will choose to reduce the retail price of their products to attract consumers to continue to purchase products in the retail channel. However, the effect of the price cuts by retailers has been very limited, and sales in the retail channel are still down compared to before. For retailers, lower retail prices and declining sales volumes ultimately lead to lower profits for retailers.

Corollary 7 also shows that as the manufacturer's cost of purchasing return shipping insurance rises, the manufacturer will set a higher direct online price to cover its cost of purchasing return shipping insurance. As the price of direct online sales increases, sales in the direct online sales channel will consequently decline, and more consumers will turn to the retail channel to buy products, with retailers taking the opportunity to increase the retail price of their products to make more profit. As manufacturers set higher prices for direct online sales, this leads to a sharp drop in sales in the direct online sales channel, which ultimately leads to a drop in manufacturer profits.

3.5. Returns Allowed and Return Shipping Insurance Purchased by the Consumer. Where returns are permitted and the consumer has taken out return shipping insurance (indicated by the superscript MC) when a consumer's online purchase does not meet expectations, the manufacturer allows the consumer to return the goods, but the return shipping insurance is purchased by the consumer. In this scenario, if the consumer's online purchase does not meet expectations and needs to be returned, the insurance company reimburses the consumer for the return shipping cost $D_d^{MC} = p_r - \theta p_d + (1-\theta)(r-s) + t/1 - \theta - \theta p_d - (1-\theta)(r-s) - t/\theta$,, and the consumer receives a utility of $r - s - t$. If the consumer's online purchase meets his or her expectations, then the consumer obtains utility $v - p_d - t$. Therefore, in a scenario where returns are allowed and consumer purchases return shipping insurance, the expected utility gained by the consumer from purchasing the product in the direct online channel is

$$U_d^{MC} = \theta(v - p_d - t) + (1-\theta)(r - s - t). \quad (17)$$

The utility gained by the consumer from purchasing the product in the retail channel is

$$U_r^{MC} = v - p_r. \quad (18)$$

In line with the previous section, considering only the case where both channels are in demand, the demand functions for the direct online channel and the retail channel are

$$\begin{aligned} D_d^{MC} &= \frac{p_r - \theta p_d + (1-\theta)(r-s) + t}{1-\theta} - \frac{\theta p_d - (1-\theta)(r-s) - t}{\theta}, \\ D_r^{MC} &= 1 - \frac{p_r - \theta p_d + (1-\theta)(r-s) + t}{1-\theta}. \end{aligned} \quad (19)$$

In this case, the manufacturer will remanufacture and resell the returned product after evaluation, where the profit functions of the retailer and manufacturer are

$$\begin{aligned} \pi_r^{MC} &= (p_r - w) D_r^{MC}, \\ \pi_d^{MC} &= (w - c) D_r^{MC} + \theta (p_d - c) D_d^{MC} + (1-\theta)(\rho - c - c_i) D_d^{MC}. \end{aligned} \quad (20)$$

Proposition 5. *The selling price, sales volume, and profit for the retailer and manufacturer in the scenario where returns are allowed and return shipping insurance is taken out by the consumer are as follows:* $p_r^{MC} = M\theta - N + c - t + 3/4$ *and* $p_d^{MC} = (\rho - r + s - c_i + 1)\theta - \rho + c + r - s + t + c_i/2\theta$, $D_r^{MC} = M + t - M\theta/4\theta - 4$ *and* $D_d^{MC} = (3N + c - 1)\ \theta - M\theta^2 - 2N - 2t/4\theta(\theta - 1)$, *and* $\pi_r^{MC} = -(M\theta - M - t)^2/16\theta - 16$ *and* $\pi_d^{MC} = F + (E + \alpha_1 c_i + \alpha_2 \rho + \alpha_3 r + \alpha_4 s + \alpha_5)\theta/8\theta(\theta - 1)$, *where* $M = \rho + r - s - c_i - 1$, $N = \rho - c + r - s - c_i$, $\alpha_1 = -10\rho + 8c - 10r + 10s - 6t + 2$, $\alpha_2 = -8c + 10r - 10s + 6t - 2$, $\alpha_3 = -8c - 10s + 6t - 2$, $\alpha_4 = 8c - 6t + 2$, $z_5 = -4t + 4$, $\alpha_5 = t^2 - 2t - 1$, $F = M^2\theta^3 - 2M(2N + t)\theta^2 - 2(N + t)^2$, *and* $E = 5c_i^2 + 5\rho^2 + 5r^2 + 5s^2 + 2c^2 + z_5 c$.

Proposition 5 leads to Corollary 8, which further analyses the impact of the probability $\partial \pi_r^{MC}/\partial\theta < 0$ of an online purchase meeting expectations on the sales price, sales volume, and profits of retailers and manufacturers in a scenario where returns are allowed and consumers purchase return shipping insurance.

Corollary 8. *The probability of an online purchase meeting expectations in a scenario where returns are allowed and return shipping insurance is purchased by the consumer. The effect of θ on the sales price, sales volume, and profit of retailers and manufacturers is as follows:* $\partial p_r^{MC}/\partial\theta < 0$ *and* $\partial p_d^{MC}/\partial\theta > 0$, $\partial D_r^{MC}/\partial\theta < 0$ *and* $\partial D_d^{MC}/\partial\theta > 0$, *and* $\partial \pi_r^{MC}/\partial\theta < 0$ *and* $\partial \pi_d^{MC}/\partial\theta > 0$.

Corollary 8 suggests that the probability of a product meeting a consumer's expectations increases as the consumer purchases it from a direct online sales channel when returns are allowed and the consumer purchases return shipping insurance. Consumers' willingness to buy products in the direct online sales channel increases, and therefore, the sales volume in the direct online sales channel will increase. At this point, the manufacturer will set a higher price for direct online sales to make more profit, while the retailer will choose to lower the retail price of the product to attract consumers to continue to buy the product in the retail channel. However, the effect of retailers' price cuts was very limited and did not undo the decline in sales in the retail channel. As sales volumes and prices fall in the retail channel, this has led to a rapid decline in retailers' profits.

The impact of the cost of remanufacturing the returned product c_i on the retailer's and manufacturer's selling prices, sales volumes, and profits is then analyzed, leading to Corollary 9.

Corollary 9. The impact of the cost of remanufacturing the returned product c_i on the retailer's and manufacturer's selling price, sales volume, and profit if returns are allowed and the consumer purchases return shipping insurance is as follows: $\partial p_r^{MC}/\partial c_i > 0$ and $\partial p_d^{MC}/\partial c_i > 0$, $\partial D_r^{MC}/\partial c_i > 0$ and $\partial D_d^{MC}/\partial c_i < 0$, and $\partial \pi_r^{MC}/\partial c_i < 0$ and $\partial \pi_d^{MC}/\partial c_i < 0$.

Corollary 9 suggests that in a scenario where returns are allowed and return shipping insurance is purchased by the consumer, as the cost of remanufacturing the returned product rises, the manufacturer will set a higher online direct selling price to cover its remanufacturing costs. As the price of direct online sales increases, sales in the direct online sales channel will consequently decrease, and more consumers will choose to purchase products in the retail channel. As manufacturers set higher prices for direct online sales, sales volumes in the direct online sales channel fall sharply, ultimately leading to lower profits for manufacturers.

Next, the impact of the cost t for consumers to purchase return shipping insurance and the return shipping reimbursement r received after purchasing return shipping insurance on retailers' and manufacturers' sales prices, sales volumes, and profits is analyzed, leading to Corollary 10.

Corollary 10. The effect of parameters r and t on the selling prices, sales volumes, and profits of retailers and manufacturers in a situation where returns are allowed and consumers purchase return shipping insurance is as follows: (1) $\partial p_r^{MC}/\partial r < 0$ and $\partial p_d^{MC}/\partial r > 0$, $\partial D_r^{MC}/\partial r < 0$ and $\partial D_d^{MC}/\partial r > 0$, and $\partial \pi_r^{MC}/\partial r < 0$ and $\partial \pi_d^{MC}/\partial r > 0$. (2) $\partial p_r^{MC}/\partial t < 0$ and $\partial p_d^{MC}/\partial t > 0$, $\partial D_r^{MC}/\partial t < 0$ and $\partial D_d^{MC}/\partial t > 0$, and $\partial \pi_r^{MC}/\partial t < 0$ and $\partial \pi_d^{MC}/\partial t > 0$.

Corollary 10 suggests that in a scenario where returns are allowed and consumers purchase return shipping insurance, the higher the return shipping reimbursement provided by the purchase of return shipping insurance, the lower the risk of consumers purchasing products in the direct online sales channel, the greater the willingness of consumers to purchase products in the direct online sales channel, and therefore, the greater the sales volume in the direct online sales channel. Higher return shipping reimbursement makes consumers more willing to buy products in online direct sales channels, so manufacturers can set higher online direct sales prices to make more profit, while retailers will choose to lower the retail price of their products to attract consumers to continue to buy products in retail channels. However, the effect of the retailers' price cuts was very limited and did not undo the decline in sales in the retail channel. For retailers, lower retail prices and declining sales volumes ultimately lead to lower profits for retailers.

4. Results

4.1. Discussion

4.1.1. Refund Strategy Selection. To analyze whether a manufacturer should offer a refund policy in the online direct sales channel, this section will provide some management insights by comparing the changes in the manufacturer's sales price, sales volume, and profit in a no return allowed (*NN*) scenario and a refund not return (*RN*) scenario.

Proposition 6. *The impact of refund policies on retailers' and manufacturers' selling prices, sales volumes, and profits is expressed as follows:*

(1) $p_r^{RN} < p_r^{NN}$, $p_d^{RN} > p_d^{NN}$, $D_r^{RN} = D_r^{NN}$, $D_d^{RN} > D_d^{NN}$, *and* $\pi_r^{RN} < \pi_r^{NN}$

(2) *When* $\varphi > \theta^2 - 2c^2/\theta(\theta - 1)$, $\pi_d^{RN} > \pi_d^{NN}$; *when* $0 < \varphi < \theta^2 - 2c^2/\theta(\theta - 1)$, $\pi_d^{RN} < \pi_d^{NN}$

Proposition 6 suggests that manufacturers set higher direct internet sales prices when they offer a refund policy in the direct internet sales channel. Manufacturers offering refund policies in the online direct sales channel can bring more sales to the online direct sales channel. Retailers will choose to reduce the retail price of their products to attract consumers to continue to purchase products in the retail channel. However, it is important to note that price reductions by retailers have a very limited effect and do not lead to an increase in sales in the retail channel, only to maintain the same sales volume. As a result, manufacturers offering refund policies in online direct sales channels will inevitably infringe on retailers' profits. However, the variation in the manufacturer's own profitability depends specifically on the residual value of the returned product. By offering a refund policy in the online direct sales channel when the residual value of returned products is low, the manufacturer will infringe on the retailer's profitability while at the same time suffering a loss of its own. Only if the residual value of the returned product is high can the manufacturer make itself more profitable by offering a refund policy in the online direct sales channel. This suggests that manufacturers should decide whether to offer a refund policy in the online direct sales channel based on the residual value of the returned product; otherwise, the action is likely to be detrimental to others.

4.1.2. Return Strategy Selection. To analyze the choice of return strategy for a manufacturer's online direct sales channel, this section will provide some management insights by comparing the changes in selling prices, sales volumes, and profits of retailers and manufacturers in the no returns allowed (*NN*) scenario and the no return shipping insurance (*MN*) scenario.

Proposition 7. *The impact of return policies on the selling prices, sales volumes, and profits of retailers and manufacturers is demonstrated by the following:*

(1) *When* $s \geq \rho - c_i$, $p_r^{MN} \geq p_r^{NN}$, $D_r^{MN} \geq D_r^{NN}$, $D_d^{MN} \leq D_d^{NN}$, $\pi_r^{MN} \geq \pi_r^{NN}$, *and* $\pi_d^{MN} \geq \pi_d^{NN}$; *when* $s \leq \rho - c_i$, $p_r^{MN} \leq p_r^{NN}$, $D_r^{MN} \leq D_r^{NN}$, $D_d^{MN} \geq D_d^{NN}$, *and* $\pi_d^{MN} \leq \pi_d^{NN}$

(2) *When* $s \leq c + c_i + \theta - \rho$, $p_d^{MN} \geq p_d^{NN}$; *when* $s \geq c + c_i + \theta - \rho$, $p_d^{MN} \leq p_d^{NN}$

(3) *When* $s \geq \rho - c_i$ *or* $s \leq \rho - c_i - 2$, $\pi_r^{MN} \geq \pi_r^{NN}$; *when* $\rho - c_i - 2 \leq s \leq \rho - c_i$, $\pi_r^{MN} \leq \pi_r^{NN}$

Proposition 7 suggests that when return shipping costs are low, that is, when $s \leq c + c_i + \theta - \rho$, *the manufacturer sets a higher selling price when offering a return policy in the online direct sales channel than when returns are not allowed. Conversely, when return shipping costs are high, manufacturers set lower selling prices when offering return policies in online direct sales channels than when returns are not allowed. When the return shipping cost is lower than the profit from remanufacturing and reselling the returned product, that is,* $s \leq \rho - c_i$, *the manufacturer sells more when the return policy is offered in the online direct sales channel than when returns are not allowed, but the profit is lower instead. When return shipping costs are higher than the profit from remanufacturing and reselling the returned product, that is,* $s \geq \rho - c_i$, *the manufacturer's selling price, sales volume, and profit are higher when the return policy is offered in the online direct sales channel than when returns are not allowed. Therefore, manufacturers need to determine whether to offer a return policy based on the cost of return shipping and the size of the marginal profit from remanufacturing and reselling the returned product.*

4.1.3. Return Shipping Insurance Strategy Selection. To analyze the strategic choice of whether to purchase return shipping insurance and whether it is purchased by the manufacturer or by the consumer, this section will provide some management insights by comparing the equilibrium results of three scenarios: allowing returns but no return shipping insurance (*MN*), allowing returns and having the manufacturer purchase return shipping insurance (*MR*), and allowing returns and having the consumer purchase return shipping insurance (*MC*).

Proposition 8. *The effect of the manufacturer's purchase of return shipping insurance on the equilibrium outcome is expressed as follows:*

(1) $p_d^{MR} \geq p_d^{MN}$

(2) *When* $0 < r \leq t/1 - \theta$, $p_r^{MR} \geq p_r^{MN}$, $D_r^{MR} \geq D_r^{MN}$, $D_d^{MR} \geq D_d^{MN}$, $\pi_r^{MR} \geq \pi_r^{MN}$, *and* $\pi_d^{MR} \leq \pi_d^{MN}$

(3) *When* $r \geq t/1 - \theta$, $p_r^{MR} \leq p_r^{MN}$, $D_r^{MR} \leq D_r^{MN}$, $D_d^{MR} \geq D_d^{MN}$, $\pi_r^{MR} \leq \pi_r^{MN}$, *and* $\pi_d^{MR} \geq \pi_d^{MN}$

Proposition 8 suggests that manufacturers will set higher prices for direct online sales when purchasing return shipping insurance compared to the no return shipping insurance scenario. This is because it will undoubtedly increase the manufacturer's costs of offering free return shipping insurance to consumers, so the manufacturer will inevitably set a higher direct internet price to cover the cost of purchasing return *shipping insurance. It is also clear from Proposition 8 that when the return shipping reimbursement received after purchasing return shipping insurance is low, the manufacturer's provision of free return shipping insurance to consumers while generating more sales for the online direct sales channel can hurt its own profits. Manufacturers offering free return shipping insurance to consumers can both generate more sales for the online direct sales channel and bring in more profit for themselves only if the return shipping reimbursement received after purchasing return shipping insurance is high. It follows that whether a manufacturer offers free return shipping insurance to consumers depends on the size of the reimbursement of return shipping costs received after purchasing return shipping insurance.*

Proposition 9. *The effect of consumer purchase of return shipping insurance on the equilibrium outcome is expressed as follows:* $p_r^{MC} \leq p_r^{MN}$, $p_d^{MC} \geq p_d^{MN}$, $D_r^{MC} \leq D_r^{MN}$, $D_d^{MC} \geq D_d^{MN}$, $\pi_r^{MC} \leq \pi_r^{MN}$, *and* $\pi_d^{MC} \geq \pi_d^{MN}$.

Proposition 9 suggests that the risk of return of products purchased in online direct sales channels is also lower when consumers purchase return shipping insurance compared to the no return shipping insurance scenario, and consumers' willingness to purchase products in online direct sales channels increases. As a result, sales volume in the direct online channel will increase, and manufacturers can take advantage of the opportunity to set higher prices for direct online sales to make more profit. As consumers become more willing to purchase products in online direct sales channels, retailers will choose to reduce the retail price of their products to attract consumers to continue purchasing products in retail channels. However, the effect of the retailers' price cuts has been very limited, and sales in the retail channel are still down compared to before. For retailers, lower retail prices and declining sales volumes ultimately lead to lower profits for retailers.

Proposition 10. *The effect of the purchase of return shipping insurance by different subjects on the equilibrium outcome is shown by the following:*

(1) $p_r^{MC} \leq p_r^{MR}$, $p_d^{MC} = p_d^{MR}$, $D_r^{MC} \leq D_r^{MR}$, *and* $D_d^{MC} \geq D_d^{MR}$
(2) *When* $r \geq s + c_i + 1 - \rho$, $\pi_r^{MC} \geq \pi_r^{MR}$, *and* $\pi_d^{MC} \geq \pi_d^{MR}$
(3) *When* $0 < r \leq s + c_i + 1 - \rho$, $\pi_r^{MC} \leq \pi_r^{MR}$, *and* $\pi_d^{MC} \leq \pi_d^{MR}$

Proposition 10 suggests that the price set by the manufacturer for direct online sales is the same whether the manufacturer purchases the return shipping insurance or the consumer purchases the return shipping insurance. However, when it is up to the consumer to purchase return shipping insurance, sales are higher in the direct online channel and lower in the retail channel in terms of both retail price and sales volume. Proposition 10 also shows that return shipping insurance should be provided free of charge by the manufacturer to the consumer when the return shipping reimbursement received after the purchase of return shipping insurance is low, at which point both the manufacturer and the retailer make a higher profit. Conversely, it will be better for consumers to purchase their own return shipping insurance when they receive higher reimbursement for return shipping costs after purchasing return shipping insurance. The findings of this study can provide good management insights into the choice of return shipping insurance purchase strategies in commercial practice.

4.1.4. Remanufacturing Strategy Selection. To explore whether manufacturers should remanufacture returned products and analyze the impact of remanufacturing costs, this section provides some management insights by comparing changes in manufacturers' selling prices, sales volumes, and profits in the no-return-allowed (*NN*) and refund-no-return (*RN*) scenarios.

Proposition 11. *The impact of returned product remanufacturing costs on retailers' and manufacturers' selling prices, sales volumes, and profitability performance is as follows:*

(1) *When* $c_i \geq \rho - s$, $p_r^{MN} \geq p_r^{NN}$, $D_r^{MN} \geq D_r^{NN}$, $D_d^{MN} \leq D_d^{NN}$, $\pi_r^{MN} \geq \pi_r^{NN}$, *and* $\pi_d^{MN} \geq \pi_d^{NN}$; *when* $c_i \leq \rho - s$, $p_r^{MN} \leq p_r^{NN}$, $D_r^{MN} \leq D_r^{NN}$, $D_d^{MN} \geq D_d^{NN}$, *and* $\pi_d^{MN} \leq \pi_d^{NN}$
(2) *When* $c_i \geq s - c - \theta + \rho$, $p_d^{MN} \geq p_d^{NN}$; *when* $c_i \leq s - c - \theta + \rho$, $p_d^{MN} \leq p_d^{NN}$
(3) *When* $c_i \geq \rho - s$ *or* $c_i \leq \rho - s - 2$, $\pi_r^{MN} \geq \pi_r^{NN}$; *when* $\rho - s - 2 \leq c_i \leq \rho - s$, $\pi_r^{MN} \leq \pi_r^{NN}$

Proposition 11 shows that when the cost of remanufacturing the returned product is higher, that is, $c_i \geq s - c - \theta + \rho$, *the manufacturer will set a higher direct network sales price when implementing a remanufacturing strategy. Conversely, when the cost of remanufacturing the returned product is low, that is,* $c_i \leq s - c - \theta + \rho$, *the manufacturer will set a lower direct network price when implementing a remanufacturing strategy. When* $c_i \geq \rho - s$, *the manufacturer's remanufacturing strategy does not result in more sales for the online direct sales channel; it does result in more profit for both the manufacturer and the retailer. Therefore, manufacturers need to decide whether to remanufacture returned products based on the cost of remanufacturing the returned product.*

4.2. Sensitivity Analysis. To verify the above theoretical model conclusions more intuitively, the model will be verified numerically by setting parameters that match reality. Depending on the conditions of the theoretical model and ensuring that the parameters are in the valid range, it may be useful to set the following selection of parameters: $c = 0.4$, $r = 0.06$, $t = 0.03$, $\theta = 0.8$, $s = 0.08$, $\varphi = 0.85$, $c_i = 0.2$, and $\rho = 0.85$. The following section analyzes the impact of the probability of a platform purchase meeting consumer demand, the cost per unit of product returned, the proportion of salvage value per unit of the returned product, and the cost of remanufacturing the returned product on the optimal decision.

4.2.1. Impact of the Probability of Consumer Demand Satisfaction. Figures 1 and 2 show the effect of the probability of the product satisfying the consumer on the optimal price and the optimal profit, respectively. As shown in Figure 1, offline retailers have seen prices fall as the probability of satisfying consumers by purchasing products online has increased. This is due to increased consumer satisfaction with online purchases and increased demand online, with offline retailers having no choice but to reduce the price at which they sell their products to attract customers. Online prices, however, vary under different return strategies, with prices rising under the *NN* strategy, *MN* strategy, *MR* strategy, and *MC* strategy and falling under the *RN* strategy. This is because the manufacturer will only allow refunds and not returns under the *RN* strategy, which will affect the consumer's online shopping experience, and the manufacturer will have no choice but to sell at a reduced price to retain customers. From Figure 1, it can be seen that manufacturers priced highest under the *MR* and *MC* strategies, followed by the *MN*, *NN*, and *RN* strategies. The reason for this is that under the *MR* strategy, the cost of return insurance is borne by the manufacturer, who raises the price of the product to cover this cost. Under the *MC* strategy, although the return insurance is paid for by the consumer, the demand from the manufacturer increases, and the manufacturer raises the price of the product to make more profit. In contrast, manufacturers in the *MN*, *NN*, and *RN* strategies do not offer return insurance or do not allow returns, which increases the risk that consumers will buy online and have to adopt a low-price strategy to attract consumers. For offline retailers, the product price is highest under the *NN* strategy with the lowest probability of meeting demand, that is, when θ is smallest, followed by the *MN* strategy, *MR* strategy, *MC* strategy, and *RN* strategy. This suggests that not allowing returns will significantly affect the manufacturer's demand, allowing the manufacturer to increase the price at which the product is sold. Under the *MN* strategy, the manufacturer does not provide free return insurance but allows returns, at which point the offline retailer can only lower the price of the product to attract consumers. Under the *MR* and *MC* strategies, manufacturers offer free return insurance to consumers or allow consumers to purchase their own insurance, greatly reducing the risk of online purchases, and offline retailers can only sell their products at lower prices to capture the customer base. Under the *RN* strategy, although the manufacturer does not provide return insurance and does not allow consumers to purchase their own return insurance, consumers can leave unsatisfactory products behind and receive a full refund from the merchant. The offline retailer sells its products at the lowest price under the *NN* strategy when the product satisfaction rate is high, that is, when θ is large. This is because when online shopping can satisfy consumers' needs to a greater extent, the convenience of online shopping will drive consumers to buy online although the merchant does not provide free return insurance, and the offline retailer can only sell its products at a reduced price. By comparing the prices of manufacturers and retailers under different strategies, it can be seen that when θ is low, the prices of offline

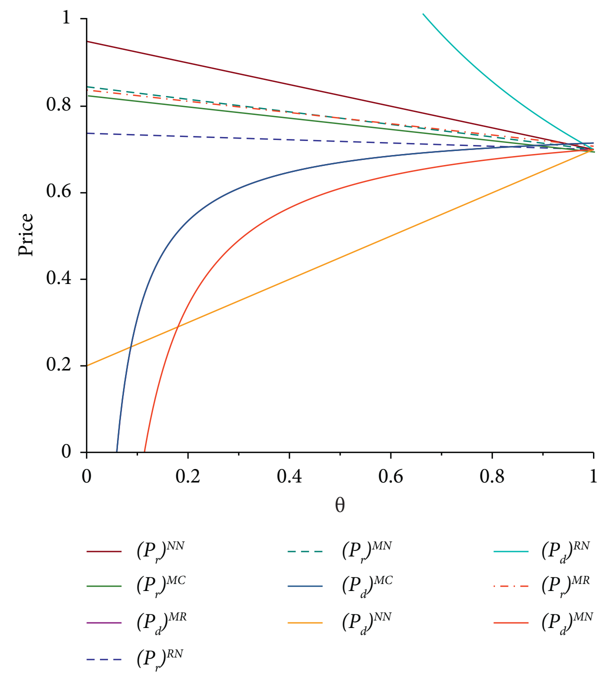

Figure 1: Effect of θ on optimal price.

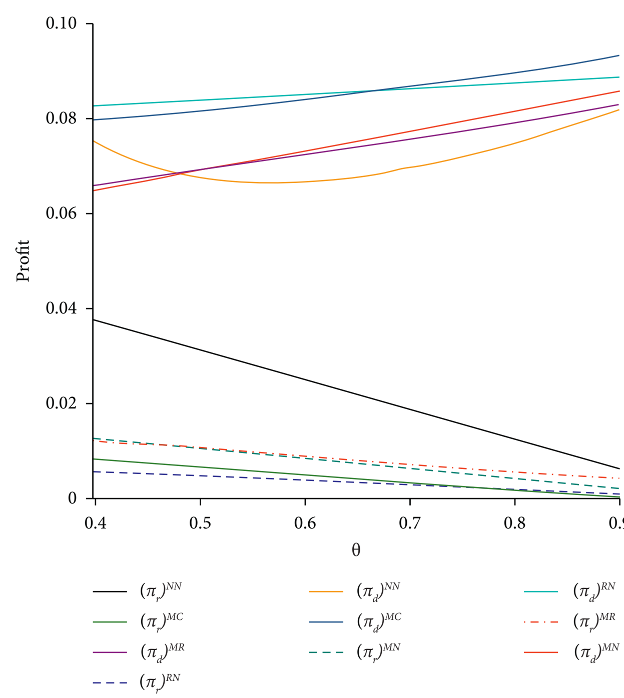

Figure 2: Effect of θ on optimal profit.

retailers are higher than those of manufacturers, and as θ increases, the prices of manufacturers will gradually be higher than those of offline retailers. When the increase in consumer satisfaction with online purchases will attract more consumers, offline retailers can only occupy the market through a low-price strategy.

As shown in Figure 2, as θ increases, the profits of the retailers all decrease, while the profits of the manufacturers all

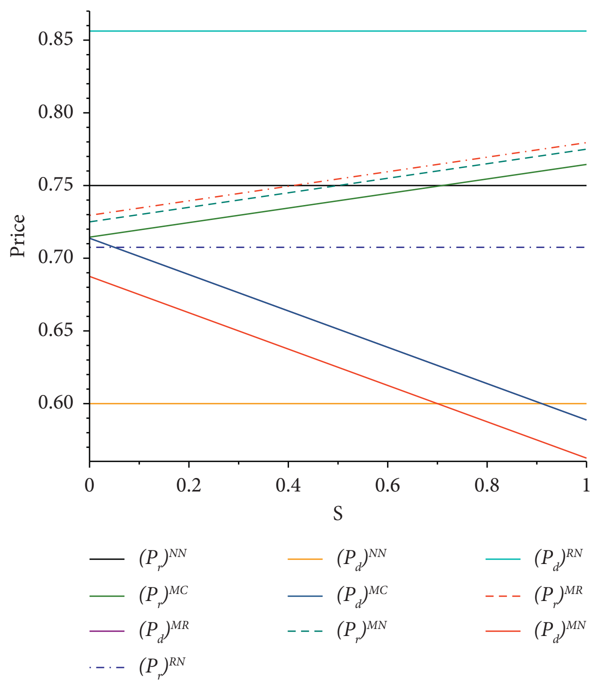

Figure 3: Effect of s on optimal price.

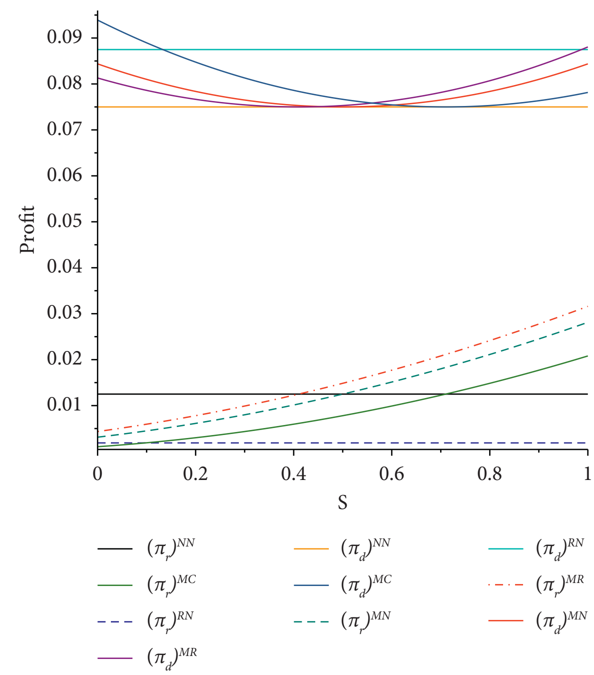

Figure 4: Effect of s on optimal profit.

increase. The reason for this is obvious: when the probability of online shopping meeting consumer demand is high, both demand and prices rise for manufacturers and fall for retailers, which leads to an upward and downward trend in profits for both manufacturers and retailers. For manufacturers, profits are highest under the *RN* strategy when θ is small because neither the manufacturer nor the consumer has to bear return costs under the *RN* strategy, and thus, demand increases, and therefore, profits are highest. Profits are highest under the *MC* strategy when θ is large. Therefore, when online shopping satisfaction is low, manufacturers should be more likely to opt for *RN* strategies, that is, offering refunds only without the need to return goods. The *MC* strategy should be chosen more often when online purchase satisfaction is high. For offline retailers, profits are highest under the *NN* strategy when θ is low, as consumers are less satisfied with their online purchases and will naturally choose to buy offline more often, increasing the profits of offline retailers accordingly. In concrete practice, therefore, both manufacturers and retailers should pay close attention to the probability that a platform purchase satisfies consumer demand, that is, θ. Offline retailers can price their goods accurately according to θ, and manufacturers should improve θ in many ways, such as the quality of goods and services, to ensure that they can have higher prices and profits.

4.2.2. Impact of Unit Product Return Costs. Figure 3 shows the impact of consumer return costs per unit of product on manufacturer and retailer sales prices in different scenarios. The graph shows that when the return cost per unit of product is low, the offline retailer has the highest selling price under the manufacturer's no returns allowed, that is, the *NN* strategy, and as the return cost per unit of product increases, the offline retailer has the highest selling price under the *MR* strategy. For manufacturers, regardless of the size of the return cost per unit of product, their selling price is highest at the time of the *RN* strategy, that is, refunds without returns, and is always higher than the selling price of offline retailers. Under the *RN* strategy, consumers can offer refunds for unsatisfactory goods but do not need to return the goods, so no return costs are incurred, and the goods left behind still have some use, hence the high demand and high selling prices of the products on the online platform under the *RN* strategy.

Figure 4 shows the impact of consumer return costs per product on manufacturer and retailer profits in different scenarios. As seen from the graph, the manufacturer's profit is always greater than the retailer's profit, regardless of the size of the return cost per unit of product and whether the manufacturer offers a return policy or return insurance. Specifically, offline retailers are most profitable when the return cost per unit of product is small and when the *NN* strategy, that is, the manufacturer does not offer a return strategy, is in place. Because the online sales channel does not allow consumers to return unsatisfactory products at this time, all losses will be borne by the consumer in the event of a failed purchase, and consumers prefer to shop offline to avoid this risk. As the cost per unit of product returned increases, the offline retailer's profits are greatest when the *MR* strategy, that is, the manufacturer, allows returns and provides return insurance. For manufacturers, the highest profit is made when the return cost per unit of product is small and when the *MC*, that is, the consumer, purchases his own return insurance. As the cost per unit of product returned increases, manufacturers are most profitable under the *RN*, refund not return strategy, and the *MR*, manufacturer-provided return insurance strategy, as neither strategy requires the consumer to bear the loss caused by the return of the product.

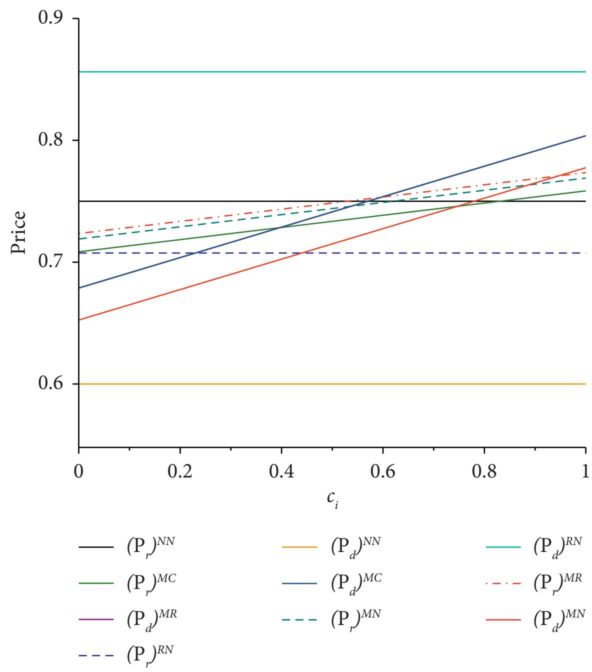

Figure 5: Effect of c_i on optimal price.

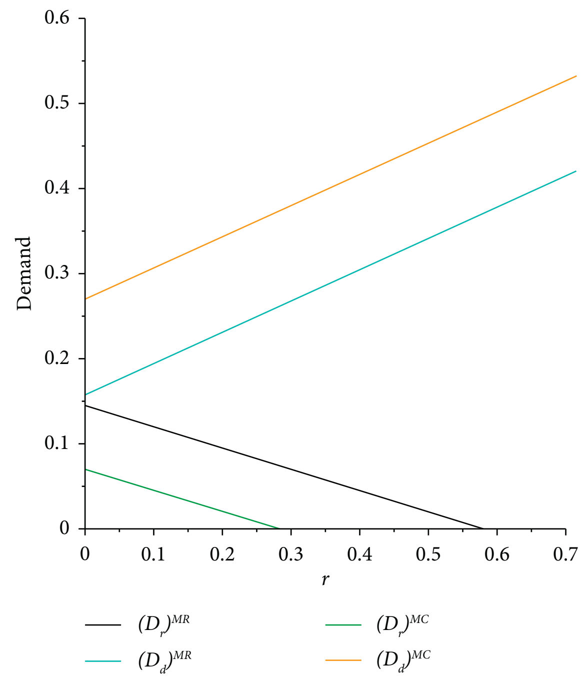

Figure 7: Effect of r on optimal demand.

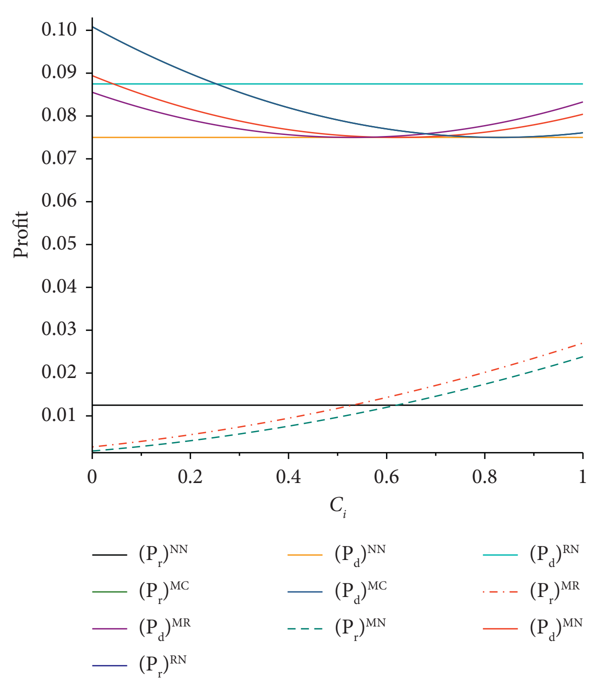

Figure 6: Effect of c_i on optimal profit.

4.2.3. Impact of Remanufacturing Costs per Unit of Returned Product. Figure 5 shows the impact of the remanufacturing cost per unit of returned product on the sales prices of manufacturers and retailers under different scenarios. As shown in the graph, when the cost of remanufacturing the returned product is small, the offline retailer's price is greatest when the *NN* strategy, that is, the manufacturer, does not allow returns. As the cost of remanufacturing returned products increases, the selling price for offline retailers is highest under the *MR* strategy when the manufacturer provides return insurance. For manufacturers, the selling price of their products is always the highest in the *RN* strategy, that is, when the manufacturer allows the consumer a refund but not a return. This is because, under this strategy, the manufacturer may lose some of the product due to consumer dissatisfaction and therefore set a higher selling price, whereas under the *NN* strategy, that is, when the manufacturer does not allow returns, the manufacturer's selling price is always the lowest.

Figure 6 shows the impact of the remanufacturing cost per unit of returned product on the profits of manufacturers and retailers in different scenarios. The graph shows that retailers' profits are highest under the *MC* strategy when the remanufacturing cost per unit of the returned product is low, that is, when consumers purchase their own return insurance, and that retailers' profits are always highest under the *MC* strategy as the remanufacturing cost per unit of returned product increases and as the return policy changes. For the manufacturer, the manufacturer's profit is highest under the *MC* strategy when the remanufacturing cost per returned product is low, and as the remanufacturing cost of the returned product increases, the manufacturer's profit is greatest under the *RN* strategy.

4.2.4. Impact and Reimbursement Return Shipping Costs after Purchase of Return Shipping Insurance and Return Shipping Costs. Figure 7 shows the impact of return shipping reimbursement on consumer demand following the purchase of return shipping insurance under the *MR* and *MC*

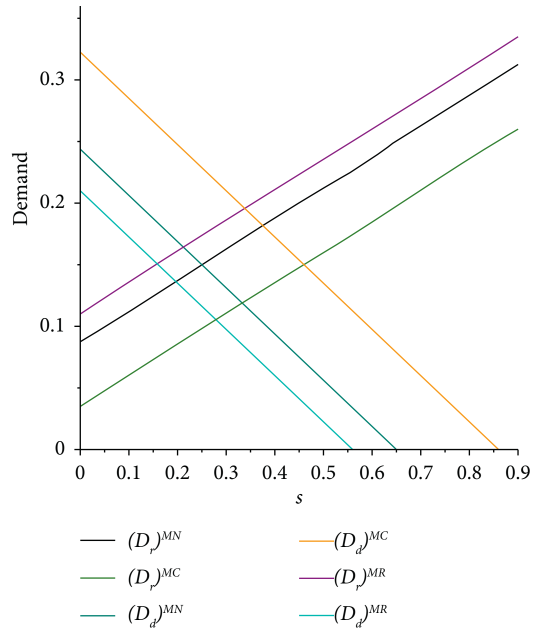

Figure 8: Effect of s on optimal demand.

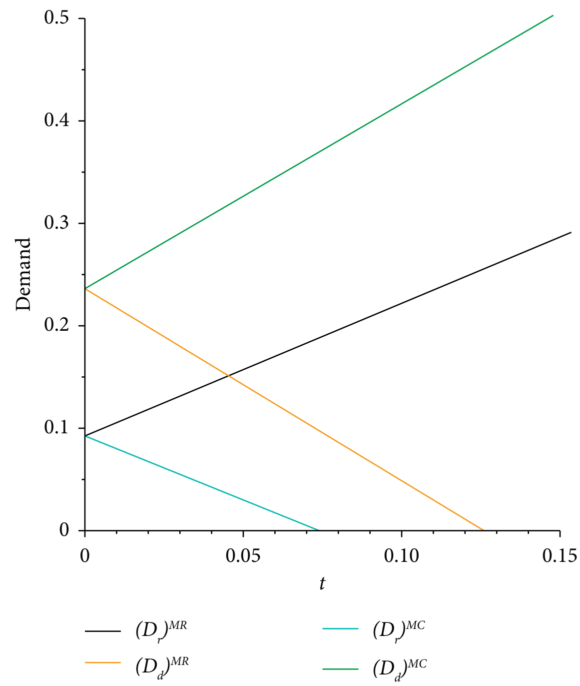

Figure 9: Effect of t on optimal demand.

strategies. As shown in the graph, under *MR* and *MC* strategies, the demand for the retailer's product decreases at the same rate as the amount of return compensation per unit of product increases, while the demand for the manufacturer's product increases monotonically and at the same rate as the amount of return compensation increases. In addition, product demand is always at a high level for manufacturers under both strategies and is higher under the *MC* strategy than the *MR* strategy. This suggests that the increasingly sophisticated return service for online sales has made consumers more inclined to choose the convenient online shopping platform when shopping, and that brick-and-mortar retail is bound to take a hit in this scenario. As a result, manufacturers can gain a larger market share by increasing the amount of compensation for product returns, and return strategies can be more profitable by allowing consumers to purchase their own return shipping insurance. For offline retailers, there is a need to ensure product quality and improve service levels to reduce the impact of e-commerce platforms.

Figure 8 shows the impact of return shipping costs on consumer demand under the *MN*, *MR*, and *MC* strategies. The graph shows that retailers' product demand and return shipping costs are positively related under the three strategies, while manufacturers' product demand and return shipping costs are negatively related. When return shipping costs are low, demand for manufacturers' products, although trending downwards, is still higher than that of retailers. With the rise in return shipping costs, manufacturers are gradually at a disadvantage in terms of sales. The obvious reason is that the high cost of return shipping increases the risk of online shopping for consumers who will turn to the more secure option of offline shopping. The graph shows that the retailer's product demand is highest under the *MR* strategy when the manufacturer will offer consumers return insurance and, accordingly, higher product prices. As a result, the demand for products under the *MR* strategy is lowest for manufacturers. Consumers are always looking for good quality products for less money, especially price-sensitive consumers. Therefore, manufacturers may choose to allow consumers to purchase their own shipping insurance to reduce the risk of online shopping, rather than offering them free shipping insurance by increasing the price of their products.

4.2.5. Effect of the Cost of Purchasing Return Shipping Insurance and the Price of Remanufacturing the Returned Product for Resale. Figure 9 shows the impact of the cost of purchasing return shipping insurance on consumer demand under the *MR* and *MC* strategies. The graph shows that under the *MR* strategy, the retailer's demand for the product increases monotonically with the cost of freight insurance; the manufacturer's demand for the product decreases monotonically with the cost of freight insurance. Under the *MC* strategy, the retailer's product decreases monotonically with the cost of freight insurance, while the manufacturer's demand increases monotonically. In terms of the magnitude of change, the change in demand for manufacturers was greater than for retailers under both strategies. This suggests that the cost of purchasing return shipping insurance has a greater impact on the manufacturer. In addition, the demand for the manufacturer's products under the *MC* strategy is always at the highest level, while the retailer's demand is at the lowest level. The reason for this is that by not providing return insurance, the manufacturer can reduce costs and therefore the selling price of the product. By capturing consumers' preferences for low prices, you can capture a favorable market. It follows that the adverse impact

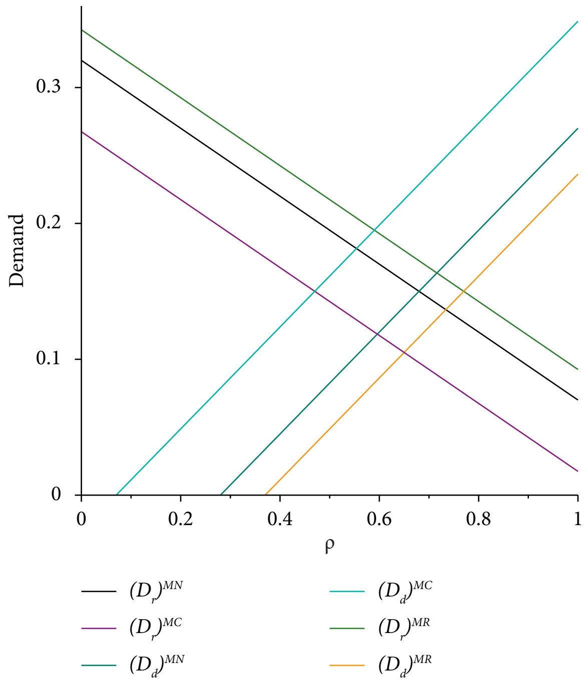

Figure 10: Effect of ρ on optimal demand.

of return shipping insurance on manufacturers can be reduced by making reasonable return policies.

Figure 10 shows the impact of the price of remanufacturing the returned product for resale under the *MN*, *MR*, and *MC* strategies on consumer demand. As shown in the graph, the retailer's product demand is negatively related to the price at which the returned product is remanufactured for resale, and conversely, the manufacturer's product demand is positively related to the price at which it is resold. Retailers have a higher demand for their products than manufacturers when the price of resale is lower. With higher sales prices, demand from manufacturers outpaced retailers and was at its highest under the *MC* strategy. This suggests that higher resale prices are more favorable to manufacturers because of the complete return service of the online sales channel. Therefore, it is more advantageous to choose online channels for the sale of returned and remanufactured products.

5. Managerial Insights and Practical Implications

Remanufacturing refers to the use of used products as blanks, using special technology and techniques to carry out new manufacturing based on the original product, the remanufactured product is no less than the new product in terms of quality and performance. Remanufacturing technology not only extends the life of products but also allows for near-zero waste of energy resources. At a time when resources and energy are relatively scarce, the advantages of remanufacturing technology cannot be ignored. In 2021, the State Council issued a guiding opinion on "accelerating the establishment of a sound green low-carbon cycle development economic system," proposing to promote industrial green upgrading, vigorously develop the remanufacturing industry, and strengthen the certification and promotion and application of remanufactured products. In the context of "double carbon," it is important to support remanufacturing in key industries to develop a green circular economy.

With the rapid growth in e-commerce transactions, the number of returns has exploded. Forecast data published by the NRF show that e-commerce returns spending will increase to US$604 billion, which will create huge pressure on warehousing. As a result, the question of how to deal with returns has become a real issue for merchants to consider. To relieve the pressure on warehousing, Amazon will advise sellers to dispose of their products for free through a donation scheme, which is undoubtedly extremely wasteful. For its part, Pangu De Ho has launched the De Ho after-sales service platform to solve overseas after-sales and returns problems for Chinese sellers. In the face of a large number of returns due to COVID-19 and other reasons, the platform has introduced four core services: return sorting, labeling and label exchange, quality inspection and refurbishment, and product repair. These services will effectively reduce the negative impact of returns on businesses and reduce environmental pressure. This paper studies the impact of returned product remanufacturing on the return strategy of supply chain members during the online sales process and provides theoretical guidance for online merchants in dealing with returns and the remanufacturing of returned products.

6. Conclusions

This paper investigates the optimal pricing decision problem for four scenarios in which the manufacturer does not offer a return strategy (*NN* strategy), the manufacturer offers a refund strategy but does not offer a return strategy (*RN* strategy), the manufacturer offers a return strategy but does not offer return insurance (*MN* strategy), the manufacturer offers a return strategy and offers return insurance (*MR* strategy), and the manufacturer offers a return strategy but the consumer purchases return insurance (*MC* strategy) under a competitive channel between the manufacturer and the retailer. The comparative study also answers the five questions of whether to offer a refund strategy, whether to offer a return strategy, whether to offer return insurance, who covers the return insurance, and what is the impact of returning recycled products on the return strategy of the supply chain members. The results of the study not only provide theoretical support for the study of the mechanism of combining return insurance and return strategy but also provide guidance for companies to develop appropriate return strategies.

Therefore, the results are as follows:

(1) Regarding whether to offer a refund strategy, by comparing the *NN* and *RN* strategies, we found that the manufacturer's selling price and product sales were always higher when offering a refund strategy, while the retailer's selling price and profits were lower. Therefore, it is more advantageous for the manufacturer to offer a refund strategy. Further

analysis of the impact of the residual value of the returned product on the manufacturer's profitability shows that when the residual value of the returned product is large, the manufacturer can make more profit by offering a refund strategy; when the residual value of the returned product is small, it is more beneficial not to offer a refund strategy.

(2) Regarding whether to offer a return strategy, a comparison of *NN* and *MN* strategies revealed that manufacturers offering return strategies sell their products at higher prices, in higher volumes, and at higher profits when the cost of return to consumers is lower. However, when the cost of return to the consumer is higher, the manufacturer's profit is reduced instead. Manufacturers can therefore choose the *MN* strategy when return shipping costs are low and the *NN* strategy when return shipping costs are high.

(3) About whether to provide return insurance, a comparison of the *MN*, *MR*, and *MC* strategies shows that manufacturers should set a higher selling price under the *MR* strategy when return compensation is greater, at which point the manufacturer should choose to provide consumers with return insurance to make more profit. When return shipping costs are high, manufacturers should choose to allow consumers to purchase their own return insurance, given the increase in price that would affect product sales if merchants offered return insurance. Further comparison of the *MR* and *MC* strategies reveals that the manufacturer's optimal selling price is the same under both strategies but that profits are higher under the *MC* strategy when the return compensation is greater when it is more advantageous for the manufacturer to have the return insurance borne by the consumer.

(4) Regarding the impact of returning remanufactured products on the return strategy of supply chain members, a comparison of *MN*, *MR*, and *MC* strategies revealed that although the increase in the cost of remanufacturing causes the manufacturer's profit to go through a process from decreasing to increasing, the manufacturer's profit is always higher than that of the retailer. When remanufacturing costs are low, the manufacturer may choose the *MC* strategy; when remanufacturing costs are high, it is more advantageous for the manufacturer to choose the *MR* strategy. Further analysis of the impact of the price of remanufactured resales of returned products on demand found that manufacturer product sales were highest under the *MC* strategy when the resale price was higher. Therefore, it is more advantageous for manufacturers to choose to allow consumers to purchase their own return insurance when selling remanufactured products in terms of the price at which the product is sold.

While this paper examines issues around whether to provide a return strategy, whether to provide return insurance, who provides return insurance, and the impact of returning recycled products on the return strategy of supply chain members and informs manufacturers' return decisions, it does not consider enough the behavior of consumers and recyclers. For example, studying consumers' willingness to accept remanufactured products, taking into account the psychological cost to consumers and the functional quality of the product,exploring the decision-making behavior of recyclers in the remanufacturing process based on carbon reduction and government subsidy policies,the relationship between consumers' willingness to buy and return services for both regular and remanufactured products, all of which will be worthy of future research.

Appendix

Proof of Proposition 1. The second-order derivatives of the profit functions of the manufacturer and the retailer with respect to p_d and p_r, respectively, are obtained: $\partial^2 \pi_d^{NN}/\partial(p_d^{NN})^2 = -2/\theta(1-\theta) < 0$ and $\partial^2 \pi_r^{NN}/\partial(p_r^{NN})^2 = -2/1-\theta < 0$. This gives the Hessian matrix $\begin{vmatrix} -2/1-\theta & 1/1-\theta \\ 1/1-\theta & -2/\theta(1-\theta) \end{vmatrix} = 4-\theta/\theta(1-\theta)^2 > 0$, that is, there is a unique optimal solution. From the first-order condition, $\partial\pi_r^{NN}/\partial p_r^{NN} = 0$; $\partial\pi_d^{NN}/\partial p_d^{NN} = 0$; and $\partial\pi_d^{NN}/\partial w = 0$. The authors have $p_r^{NN} = 3+2c-\theta/4$, $p_d^{NN} = \theta + c/2$, and $w = c + 1/2$. Substituting p_r^{NN}, p_d^{NN}, and w into the demand and profit functions gives the optimal demand and profit for retailers and manufacturers.

Proof of Corollary 1. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to θ to give $\partial p_r^{NN}/\partial\theta = -1/4 < 0$, $\partial p_d^{NN}/\partial\theta = 1/2 > 0$, $\partial D_r^{NN}/\partial\theta = 0$, $\partial D_d^{NN}/\partial\theta = c/2\theta^2 > 0$, $\partial\pi_r^{NN}/\partial\theta = -1/16 < 0$, and $\partial\pi_d^{NN}/\partial\theta = \theta^2 - 2c^2/8\theta^2 > 0$.

Proof of Proposition 2. The second-order derivatives of the profit functions of the manufacturer and the retailer with respect to p_d and p_r, respectively, are obtained: $\partial^2\pi_d^{RN}/\partial(p_d^{RN})^2 = 2\theta^2/(\varphi-1)(\theta-1)(\theta\varphi-\theta-\varphi) < 0$ and $\partial^2\pi_r^{RN}/\partial(p_r^{RN})^2 = -2/(1-\varphi)(1-\theta) < 0$. This gives the Hessian matrix-
$\left|\% \begin{matrix} -2/(1-\theta)(1-\varphi) & \theta/(1-\theta)(1-\varphi) \\ \theta/(1-\theta)(1-\varphi) & 2\theta^2/(\varphi-1)(\theta-1)(\theta\varphi-\theta-\varphi) \end{matrix}\right| = -\theta^2(\theta\varphi-\theta-\varphi+4)/(\varphi-1)^2(\theta-1)^2(\theta\varphi-\theta-\varphi) > 0$, that is, there is a unique optimal solution. From the first-order condition, $\partial\pi_r^{RN}/\partial p_r^{RN} = 0$; $\partial\pi_d^{RN}/\partial p_d^{RN} = 0$; and $\partial\pi_d^{RN}/\partial w = 0$. The authors have $p_r^{RN} = (\theta-1)\varphi + 2c + 3 - \theta/4$, $p_d^{RN} = \theta + c + \varphi - \theta\varphi/2\theta$, and $w = c + 1/2$. Substituting p_r^{RN}, p_d^{RN}, and w into the demand and profit functions gives the optimal demand and profit for retailers and manufacturers.

Proof of Corollary 2. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to θ to give $\partial p_r^{RN}/\partial\theta =$

$\varphi - 1/4 < 0$ and $\partial p_d^{RN}/\partial\theta = -c - \varphi/2\theta^2 < 0$; $\partial D_r^{RN}/\partial\theta = 0$ and $\partial D_d^{RN}/\partial\theta = -(\varphi - 1)c/2(\theta\varphi - \varphi - \theta)^2 > 0$; and $\partial\pi_r^{RN}/\partial\theta = \varphi - 1/16 < 0$ and $\partial\pi_d^{RN}/\partial\theta = (2\varphi(\theta^2 - \theta) - (\theta - 1)^2\varphi^2 + 2c^2 - \theta^2)(\varphi - 1)/8(\theta\varphi - \varphi - \theta)^2 > 0$.

Proof of Proposition 3. The second-order derivatives of the profit functions of the manufacturer and the retailer with respect to p_d and p_r, respectively, are obtained: $\partial^2\pi_d^{MN}/\partial(p_d^{MN})^2 = 2\theta/\theta - 1 < 0$ and $\partial^2\pi_r^{MN}/\partial(p_r^{MN})^2 = -2/1 - \theta < 0$. This gives the Hessian matrix $\begin{vmatrix} -2/1-\theta & \theta/1-\theta \\ \theta/1-\theta & 2\theta/\theta-1 \end{vmatrix} = -\theta(\theta - 4)/(\theta - 1)^2 > 0$, that is, there is a unique optimal solution. From the first-order condition, $\partial\pi_r^{MN}/\partial p_r^{MN} = 0$; $\partial\pi_d^{MN}/\partial p_d^{MN} = 0$; and $\partial\pi_d^{MN}/\partial w = 0$. The authors have $p_r^{MN} = \rho\theta - c_i\theta - s\theta - \rho + 2c + c_i + s - \theta + 3/4$, $p_d^{MN} = \rho\theta - c_i\theta + s\theta - \rho + c + c_i - s + \theta/2\theta$, and $w = c + 1/2$. Substituting p_r^{MN}, p_d^{MN}, and w into the demand and profit functions gives the optimal demand and profit for retailers and manufacturers.

Proof of Corollary 3. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to θ to give $\partial p_r^{MN}/\partial\theta = \rho - c_i - s - 1/4 < 0$ and $\partial p_d^{MN}/\partial\theta = \rho - c_i - c + s/2\theta^2 > 0$, $\partial D_r^{MN}/\partial\theta = 0$ and $\partial D_d^{MN}/\partial\theta = c + c_i + s - \rho/2\theta^2 > 0$, and $\partial\pi_r^{MN}/\partial\theta = -(\rho - c_i - s - 1)^2/16 < 0$ and $\partial\pi_d^{MN}/\partial\theta = (\rho - c_i - s - 1)^2\theta^2 - 2(\rho - c - c_i - s)^2/8\theta^2 > 0$. □

Proof of Corollary 4. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to c_i to give $\partial p_r^{MN}/\partial c_i = 1 - \theta/4 > 0$ and $\partial p_d^{MN}/\partial c_i = 1 - \theta/2\theta > 0$, $\partial D_r^{MN}/\partial c_i = 1/4 > 0$ and $\partial D_d^{MN}/\partial c_i = \theta - 2/4\theta < 0$, and $\partial\pi_r^{MN}/\partial c_i = (\rho - s - c_i - 1)(\theta - 1)/8 > 0$ and $\partial\pi_d^{MN}/\partial c_i = (1 - \theta)((\rho - s - c_i - 1)\theta - 2(\rho - c - c_i - s))/4\theta > 0$.

Proof of Proposition 4. The second-order derivatives of the profit functions of the manufacturer and the retailer with respect to p_d and p_r, respectively, are obtained: $\partial^2\pi_d^{MR}/\partial(p_d^{MR})^2 = 2\theta/\theta - 1 < 0$ and $\partial^2\pi_r^{MR}/\partial(p_r^{MR})^2 = -2/1 - \theta < 0$. This gives the Hessian matrix $\begin{vmatrix} -2/1-\theta & \theta/1-\theta \\ \theta/1-\theta & 2\theta/\theta-1 \end{vmatrix} = -\theta(\theta - 4)/(\theta - 1)^2 > 0$, that is, there is a unique optimal solution. From the first-order condition, $\partial\pi_r^{MR}/\partial p_r^{MR} = 0$; $\partial\pi_d^{MR}/\partial p_d^{MR} = 0$; and $\partial\pi_d^{MR}/\partial w = 0$. The authors have $p_r^{MR} = (\rho + r - s - c_i - 1)\theta - \rho + 2c - r + s + t + c_i + 3/4$, $p_d^{MR} = (\rho - r + s - c_i + 1)\theta - \rho + c + r - s + t + c_i/2\theta$, and $w = c + 1/2$. Substituting p_r^{MR}, p_d^{MR}, and w into the demand and profit functions gives the optimal demand and profit for retailers and manufacturers.

Proof of Corollary 5. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to θ to give $\partial p_r^{MR}/\partial\theta = \rho + r - c_i - s - 1/4 < 0$ and $\partial p_d^{MR}/\partial\theta = \rho - c - r - c_i - t + s/2\theta^2 > 0$, $\partial D_r^{MR}/\partial\theta = t/4(\theta - 1)^2 > 0$ and $\partial D_d^{MR}/\partial\theta = (-2\rho + 2c - 2r + 2c_i + t + 2s)\theta^2 + (\rho - c + r - s - t - c_i)(4\theta - 2)/4\theta^2(\theta - 1)^2 > 0$, and $\partial\pi_r^{MR}/\partial\theta = -((\rho + r - s - c_i - 1)\theta - \rho - r + s - t + c_i + 1)\ ((\rho + r - s - c_i - 1)\theta - \rho - r + s + t + c_i + 1)/\ 16(\theta - 1)^2 < 0$; to simplify the formula, let $x = \rho + r - s - c_i - 1$, $y = \rho - c + r - s - c_i$, $\beta_1 = 2\rho - 4c + 2r - 2s - 4t + 2$, $\beta_2 = 4c - 2r + 2s + 4t - 2$, $\beta_3 = 4c + 2s + 4t - 2$, $\beta_4 = -4c - 4t + 2$, and $\beta_5 = -2c^2 - 4ct - t^2 + 1$; the derivative of the manufacturer's optimum profit with respect to θ is then simplified as $\partial\pi_d^{MR}/\partial\theta = x^2\theta^4 - 2x^2\theta^3 + (-c_i^2 + \beta_1 c_i - \rho^2 + \beta_2\rho - r^2 + \beta_3 r - s^2 + \beta_4 s + \beta_5)\theta^2 + (4\theta - 2)(y - t)^2/8\theta^2(\theta - 1)^2 > 0$.

Proof of Corollary 6. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to c_i to give $\partial p_r^{MR}/\partial c_i = > 0$ and $\partial p_d^{MR}/\partial c_i = 1 - \theta/2\theta > 0$, $\partial D_r^{MR}/\partial c_i = 1/4 > 0$ and $\partial D_d^{MR}/\partial c_i = \theta - 2/4\theta < 0$, and $\partial p_d^{MR}/\partial c_i = (\rho + r - c_i - s - 1)\theta - (\rho + r - s - t - c_i - 1)/8 > 0$ and $\partial\pi_d^{MR}/\partial c_i = (s + c_i - r - \rho + 1)\theta^2 + (3\rho - 2c + 3r - 3s - t - 3c_i - 1)\theta - 2(\rho - c + r - s - t - c_i)/4\theta < 0$.

Proof of Corollary 7. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to r to give $\partial p_r^{MR}/\partial r = \theta - 1/4 < 0$ and $\partial p_d^{MR}/\partial r = 1 - \theta/2\theta > 0$, $\partial D_r^{MR}/\partial r = -1/4 < 0$ and $\partial D_d^{MR}/\partial r = 2 - \theta/4\theta > 0$, and $\partial\pi_r^{MR}/\partial r = (s - \rho - r + c_i + 1)\theta + (\rho + r - s - t - c_i - 1)/8 < 0$ and $\partial\pi_d^{MR}/\partial r = (\rho + r - s - c_i - 1)\theta^2 + (2c - 3\rho - 3r + 3s + t + 3c_i + 1)\theta + 2(\rho - c + r - s - t - c_i)/4\theta > 0$.

The optimal selling price, the optimal demand, and the optimal profit for the manufacturer and the retailer are each derived with respect to t to give: $\partial p_r^{MR}/\partial t = 1/4 > 0$ and $\partial p_d^{MR}/\partial t = 1/2\theta > 0$, $\partial D_r^{MR}/\partial t = -1/4(\theta - 1) > 0$ and $\partial D_d^{MR}/\partial t = 2 - \theta/4\theta(\theta - 1) < 0$, and $\partial\pi_r^{MR}/\partial t = (s - \rho - r + c_i + 1)\theta + (\rho + r - s - t - c_i - 1)/8(\theta - 1) > 0$ and $\partial\pi_d^{MR}/\partial t = (\rho + r - s - c_i - 1)\theta^2 + (2c - 3\rho - 3r + 3s + t + 3c_i + 1)\theta + 2(\rho - c + r - s - t - c_i)/4\theta(\theta - 1) < 0$.

Proof of Proposition 5. The second-order derivatives of the profit functions of the manufacturer and the retailer with respect to p_d and p_r, respectively, are obtained: $\partial^2\pi_d^{MC}/\partial(p_d^{MC})^2 = 2\theta/\theta - 1 < 0$ and $\partial^2\pi_r^{MC}/\partial(p_r^{MC})^2 = -2/1 - \theta < 0$. This gives the Hessian matrix $\begin{vmatrix} -2/1-\theta & \theta/1-\theta \\ \theta/1-\theta & 2\theta/\theta-1 \end{vmatrix} = -\theta(\theta - 4)/(\theta - 1)^2 > 0$, that is, there is a unique optimal solution. From the first-order condition, $\partial\pi_r^{MC}/\partial p_r^{MC} = 0$; $\partial\pi_d^{MC}/\partial p_d^{MC} = 0$; and $\partial\pi_d^{MC}/\partial w = 0$. The authors have $p_r^{MC} = (\rho + r - s - c_i - 1)\ \theta - \rho + 2c - r + s - t + c_i + 3/4$, $p_d^{MC} = (\rho - r + s - c_i + 1)\ \theta - \rho + c + r - s + t + c_i/2\theta$, and $w = c + 1/2$.Substituting p_r^{MC}, p_d^{MC}, and w into the demand and profit functions gives the optimal demand and profit for retailers and manufacturers.

Proof of Corollary 8. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to θ to give $\partial p_r^{MC}/\partial\theta = \rho + r - c_i - s - 1/4 < 0$ and $\partial p_d^{MC}/\partial\theta = \rho - c - c_i - r$

$-t + s/2\theta^2 > 0$, $\partial D_r^{MC}/\partial\theta = -t/4\ (\theta-1)^2 < 0$ and $\partial D_d^{MR}/\partial\theta = (-2\rho + 2c - 2r + 2c_i - t + 2s)\theta^2 + (\rho - c + r - s + t - c_i)(4\theta - 2)/4\theta^2(\theta-1)^2 > 0$, and $\partial\pi_r^{MC}/\partial\theta = -((\rho + r - s - c_i - 1)\theta - \rho - r + s + t + c_i + 1)((\rho + r - s - c_i - 1)\theta - \rho - r + s - t + c_i + 1)/16(\theta-1)^2 < 0$; to simplify the formula, let $x = \rho + r - s - c_i - 1$, $y = \rho - c + r - s - c_i$, $\lambda_1 = 2\rho - 4c + 2r - 2s + 4t + 2$, $\lambda_2 = 4c - 2r + 2s - 4t - 2$, $\lambda_3 = 4c + 2s - 4t - 2$, $\lambda_4 = -4c + 4t + 2$, and $\lambda_5 = -2c^2 + 4ct - t^2 + 1$; the derivative of the manufacturer's optimum profit with respect to θ is then simplified as $\partial\pi_d^{MC}/\partial\theta = x^2\theta^4 - 2x^2\theta^3 + (-c_i^2 + \lambda_1 c_i - \rho^2 + \lambda_2\rho - r^2 + \lambda_3 r - s^2 + \lambda_4 s + \lambda_5)\theta^2 + (4\theta-2)(y+t)^2/8\theta^2(\theta-1)^2 > 0$.

Proof of Corollary 9. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to c_i to give $\partial p_r^{MC}/\partial c_i = 1 - \theta/4 > 0$ and $\partial p_d^{MC}/\partial c_i = 1 - \theta/2\theta > 0$, $\partial D_r^{MC}/\partial c_i = 1/4 > 0$ and $\partial D_d^{MC}/\partial c_i = \theta - 2/4\theta < 0$, and $\partial\pi_r^{MC}/\partial c_i = (\rho - s + r - c_i - 1)\theta - (\rho + r - s + t - c_i - 1)/8 < 0$ and $\partial\pi_d^{MC}/\partial c_i = (s + c_i - r - \rho + 1)\theta^2 + (3\rho - 2c + 3r - 3s - 3c_i + t - 1)\theta - 2\ (\rho - c + r - s + t - c_i)/4\theta < 0$.

Proof of Corollary 10. The optimal selling price, the optimal demand, and the optimal profit of the manufacturer and the retailer are derived with respect to r to give $\partial p_r^{MC}/\partial r = \theta - 1/4 < 0$ and $\partial p_d^{MC}/\partial r = 1 - \theta/2\theta > 0$, $\partial D_r^{MC}/\partial r = -1/4 < 0$, $\partial D_d^{MC}/\partial r = 2 - \theta/4\theta > 0$, and $\partial\pi_r^{MC}/\partial r = (s - \rho - r + c_i + 1)\theta + (\rho + r - s + t - c_i - 1)/8 < 0$ and $\partial\pi_d^{MC}/\partial r = (\rho + r - s - c_i - 1)\theta^2 + (2c - 3\rho - 3r + 3s + 3c_i - t + 1)\theta + 2(\rho - c + r - s + t - c_i)/4\theta > 0$.

The optimal selling price, the optimal demand, and the optimal profit for the manufacturer and the retailer are each derived with respect to t to give $\partial p_r^{MC}/\partial t = -1/4 < 0$ and $\partial p_d^{MC}/\partial t = 1/2\theta > 0$, $\partial D_r^{MC}/\partial t = 1/4(\theta-1) < 0$ and $\partial D_d^{MC}/\partial t = \theta - 2/4\theta(\theta-1) > 0$, and $\partial\pi_r^{MC}/\partial t = (\rho + r - s - c_i - 1)\theta - (\rho + r - s + t - c_i - 1)/8(\theta-1) < 0$ and $\partial\pi_d^{MC}/\partial t = (s - \rho - r + c_i + 1)\theta^2 + (3\rho - 2c + 3r - 3s - 3c_i + t - 1)\theta + 2(\rho - c + r - s + t - c_i)/4\theta(\theta-1) > 0$.

Proof of Proposition 6. The sales prices, market shares, and profit differentials between manufacturers and retailers under the *NN* and *RN* strategies are as follows: $p_r^{RN} - p_r^{NN} = (\theta-1)\varphi/4$ and $p_d^{RN} - p_d^{NN} = -(\theta-1)(\theta + c + \varphi)/2\theta$, $D_r^{RN} - D_r^{NN} = 0$ and $D_d^{RN} - D_d^{NN} = c\varphi(\theta-1)/2\theta((\varphi-1)\theta - \varphi)$, and $\pi_r^{RN} - \pi_r^{NN} = \varphi(\theta-1)/16$ and $\pi_d^{RN} - \pi_d^{NN} = -\varphi(\theta-1)(\varphi\theta^2 + 2c^2 - \theta^2 - \theta\varphi)/8\theta((\varphi-1)\theta - \varphi)$.

Since $0 < \varphi < 1$, $0 < \varphi < 1$, therefore, $P_r^{RN} < P_r^{NN}$, $P_d^{RN} > P_d^{NN}$, $D_r^{RN} = D_r^{NN}$, $D_d^{RN} > D_d^{NN}$, and $\pi_r^{RN} < \pi_r^{NN}$.

When $\varphi > \theta^2 - 2c^2/\theta(\theta-1)$, $\pi_d^{RN} > \pi_d^{NN}$; when $0 < \varphi < \theta^2 - 2c^2/\theta(\theta-1)$, $\pi_d^{RN} < \pi_d^{NN}$.

Proof of Proposition 7. The sales prices, market shares, and profit differentials between manufacturers and retailers under the *NN* and *MN* strategies are as follows: $p_r^{MN} - p_r^{NN} = (\theta-1)(\rho - c_i - s)/4$ and $p_d^{MN} - p_d^{NN} = (\theta-1)(\rho - \theta - c - c_i + s)/2\theta$, $D_r^{MN} - D_r^{NN} = s + c_i - \rho/4$ and $D_d^{MN} - D_d^{NN} = -(\theta-2)(\rho - c_i - s)/4\theta$, and $\pi_r^{MN} - \pi_r^{NN} = -(\theta-1)(\rho - c_i - s)(\rho - s - c_i - 2)/16$ and $\pi_d^{MN} - \pi_d^{NN} = (\theta - 1)((\rho - s - c_i - 2)\theta - 2\rho + 4c + 2s + 2c_i)(\rho - s - c_i)/8\theta$.

Proof of Proposition 8. The sales prices, market shares, and profit differences between manufacturers and retailers under the *MR* and *MN* strategies are as follows: $p_r^{MR} - p_r^{MN} = (\theta-1)r + t/4$ and $p_d^{MR} - p_d^{MN} = (1-\theta)r + t/2\theta$, $D_r^{MR} - D_r^{MN} = (1-\theta)r - t/4(\theta-1)$ and $D_d^{MR} - D_d^{MN} = -(\theta-2)(\theta r - r + t)/4\theta(\theta-1)$, and $\pi_r^{MR} - \pi_r^{MN} = -((2\rho + r - 2s - 2c_i - 2)\theta - 2\rho - r + 2s + t + 2c_i + 2)(\theta r - r + t)/16(\theta-1)$ and $\pi_d^{MR} - \pi_d^{MN} = ((\rho + r/2 - s - c_i - 1)\theta^2 + (2c - 3\rho - 3r/2 + 3s + t/2 + 3c_i + 1)\theta + 2(\rho - c - s - c_i) + r - t)(\theta r - r + t)/4\theta(\theta-1)$.

Proof of Proposition 9. The sales prices, market shares, and profit differentials between manufacturers and retailers under the *MC* and *MN* strategies are as follows: $p_r^{MC} - p_r^{MN} = (\theta-1)r - t/4$ and $p_d^{MC} - p_d^{MN} = (1-\theta)r + t/2\theta$, $D_r^{MC} - D_r^{MN} = (1-\theta)r + t/4(\theta-1)$ and $D_d^{MC} - D_d^{MN} = -(\theta-2)(r\theta - r - t)/4\theta(\theta-1)$, and $\pi_r^{MC} - \pi_r^{MN} = -((2\rho + r - 2s - 2c_i - 2)\theta - 2\rho - r + 2s - t + 2c_i + 2)(\theta r - r - t)/16(\theta-1)$ and $\pi_d^{MC} - \pi_d^{MN} = (\theta r - r - t)\ ((\rho + r/2 - s - c_i - 1)\theta^2 + (2c - 3\rho - 3r/2 + 3s - t/2 + 3c_i + 1)\theta + 2(\rho - c - s - c_i) + r - t)/4\theta(\theta-1)$.

Proof of Proposition 10. The difference in selling prices, market shares, and profits between manufacturers and retailers under the *MC* and *MR* strategies are as follows: $p_r^{MC} - p_r^{MR} = -t/2$ and $p_d^{MC} - p_d^{MR} = 0$, $D_r^{MC} - D_r^{MR} = t/2(\theta-1)$ and $D_d^{MC} - D_d^{MR} = t(\theta-2)/2\theta(\theta-1)$, and $\pi_r^{MC} - \pi_r^{MR} = (\rho + r - s - c_i - 1)t/4$ and $\pi_d^{MC} - \pi_d^{MR} = t((\rho + r - s - c_i)(2-\theta) + 2c - \theta)/2\theta$.

Proof of Proposition 11. The sales prices, market shares, and profit differentials between manufacturers and retailers under the *NN* and *MN* strategies are as follows: $p_r^{MN} - p_r^{NN} = (\theta-1)(\rho - c_i - s)/4$ and $p_d^{MN} - p_d^{NN} = (\theta-1)(\rho - \theta - c - c_i + s)/2\theta$, $D_r^{MN} - D_r^{NN} = s + c_i - \rho/4$ and $D_d^{MN} - D_d^{NN} = -(\theta-2)(\rho - c_i - s)/4\theta$, and $\pi_r^{MN} - \pi_r^{NN} = -(\theta-1)(\rho - c_i - s)(\rho - s - c_i - 2)/16$ and $\pi_d^{MN} - \pi_d^{NN} = (\theta-1)((\rho - s - c_i - 2)\theta - 2\rho + 4c + 2s + 2c_i)\ (\rho - s - c_i)/8\theta$.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Algorithm Design of Port Cargo Throughput Forecast Based on the ES-Markov Model

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At present, the existing prediction algorithm of a port cargo throughput neglects the correction of the initial value of the cargo series data model, which leads to a large error in a port cargo throughput prediction. Therefore, a prediction algorithm of a port cargo throughput based on the ES-Markov model is designed. A decompose function is used to decompose the time series of a port cargo throughput, and the trend elements of a port cargo throughput are divided into long-term trend, seasonal trend, fluctuation trend, and irregular trend. In this study, the ES-Markov model is introduced, and the initial prediction is obtained by using the cubic exponential smoothing method, and the state transition matrix is obtained by the Markov principle. Based on the results of the time-series analysis and the ES-Markov model, the prediction algorithm of a port cargo throughput is designed. In the experimental design, the Elman neural network is used to construct an experimental sample data model. The monthly cargo throughput data of a certain port for eight months from May 2020 to December 2020 are collected and sorted according to the time series. The experimental results show that the prediction results of the proposed algorithm are closer to the actual value and the fluctuation of the prediction results is less than that of the reference.

1. Introduction

Since the beginning of the 21st century, the rapid development of economic globalization has deeply affected the development of the production and transportation industries, and regional economic integration has been developing with the tide. As an important economic and transportation hub, the central strategic position of ports has become prominent [1–5]. Historically, the first generation of ports has been an important transport hub, with its main functions being the conversion of means of transport and the transfer of goods, where large quantities of goods are concentrated, and the movement of goods is bound to promote economic development; the second generation of ports, in turn, has added commercial services to the first generation, thus spawning new processing industries and further promoting industrial development, and the third generation of ports, in turn, has eliminated the obvious monopoly of information between cities, cargo owners, and consumers, but has made their links more frequent, and port services have not been limited to trans-shipment of goods, but have increased services such as real-time inquiries about cargo information and commodity distribution, at a time when ports have assumed a central position in international logistics and promoted the development of international trade [6–11]. So far, the port has developed to the fourth generation, the port development mode is the most efficient, that is, the supply chain mode serving the integration of trade, manufacturing industry, and logistics. Nowadays, the aim of intelligent port is to improve the efficiency of port operation and management, which is also a test of port construction and management [12–16]. The accurate forecast of a cargo throughput provides a basis for the planning, deployment, and reasonable allocation of tasks in advance, avoids the occurrence of a cargo backlog in the port, does not affect the delivery of goods and customer satisfaction, and fully improves the operating efficiency of the port, forming a virtuous circle [22–24]. Therefore, accurate and reasonable forecast of a port cargo throughput is very important for port layout and even transformation and upgrading.

Li et al. [25] argue that the ant colony algorithm is used to optimize the initial weight and threshold of back-propagation neural network, and a prediction model is established to predict the port cargo throughput. The ant colony algorithm has the characteristics of global search ability, distributed computing, and strong robustness. It is conducive to accelerate the convergence speed of back-propagation neural network, avoid the problem of easy falling into local extremum, and improve the modeling accuracy.

Chen et al. [26] studied and analyzed the main index factors affecting the port throughput. On the basis of the SVM prediction method, the genetic algorithm (GA) and grid search algorithm (GS) are used to optimize and improve the main parameters of the SVM model. The prediction results of the GA-SVM and GS-SVM models are based on the SVM prediction method, and the genetic algorithm and GS method are used to optimize and improve the main parameters of the SVM model; the prediction results of genetic support vector machine and GS support vector machine are tested by MSE and R2. The improved SVM model is a new port throughput prediction method based on the current research results, which can be popularized and applied in the overall port planning.

Wang et al. [27] proposed a dynamic three-parameter grey prediction model. Firstly, the model parameters are estimated directly by difference equation. Then, the TPGM (1, 1) prediction model is constructed based on the model parameter values. Finally, combined with the idea of metabolism, the old data are discarded and the predicted value is added as a new original data sequence for modeling, so as to realize the dynamic prediction of passenger throughput of civil airport.

Shankar et al. [28] used the deep learning method to predict the container throughput, and the performance of other traditional time-series methods is compared. This study uses long-term and short-term memory (LSTM) network to predict container throughput. The container throughput data of Singapore port are used for empirical analysis. The prediction performance of the LSTM model is compared with seven different time-series prediction methods: autoregressive comprehensive moving average (ARIMA), simple exponential smoothing, Holt winter, error trend seasonality, triangular regression (tbats), neural network (NN), and ARIMA + NN.

However, the above reference algorithm ignores the correction of the initial value of the cargo sequence data model, resulting in large errors in the prediction results of a port cargo throughput. Therefore, we mainly aim to design a port cargo throughput prediction algorithm based on the ES-Markov model.

2. Literature Review

Using big data, Ouyang [6] demonstrated that the selection of the data fusion for the port logistics supply chain integrated management model is rational. It suggests that the logic of the mode selection for integrated management of the port logistics supply chain is more accurate and that the capability for integrated management of the port logistics supply chain in the context of the Internet of Things is enhanced.

The gross ocean product, port cargo throughput, and container throughput in coastal areas are the three key components of Liu's grey model first-order one variable (GM [1]) model forecast of the port and marine engineering economics, which was created according to the grey theory. It will be possible to comprehend and anticipate the ports throughput accurately using the GM (1, 1) model. This study concluded by making some recommendations on how to more effectively carry out the economic growth of port and marine engineering.

In the context of a Smart Port-City, Lacalle et al. [17] suggested an IoT-based software architecture together with a methodology for designing, computing, and forecasting composite indicators that represent real-world occurrences. In their study, the framework is envisioned, developed, and applied to a genuine use case as a practical experiment. The initiative involves setting up a composite index to track traffic congestion at Thessaloniki's port-city interface (Greece). Results met expectations, were confirmed by nine scenarios, and culminated in the delivery of a practical tool that interested parties at Smart Port-Cities can be used to explore and develop policy.

Long short-term memory (LSTM) networks were used by Shankar et al. [28] to anticipate container throughput. For empirical study, the container throughput data from the Port of Singapore were used. The performance of the LSTM model was compared to that of seven other time-series forecasting techniques, including the neural network (NN), ARIMA + NN, Holt Winter's, error-trend-seasonality, trigonometric regressors (TBATS), and simple exponential smoothing. The performance of the various models was examined with regard to bias, accuracy, and uncertainty using the relative error matrix. The outcomes revealed that LSTM performed better than any other benchmark technique.

To the best of our knowledge, despite the potentials of the ES-Markov model, it has not yet been employed to design a port cargo throughput prediction algorithm and such a gap can be removed by the present study and following research.

3. Problem Statement

The port cargo throughput reflects not only a country's local economic development but also a measure of a country's financial and trade development of the key indicators. In order to accurately predict a port cargo throughput, the first task is to analyze the time series of a port cargo throughput.

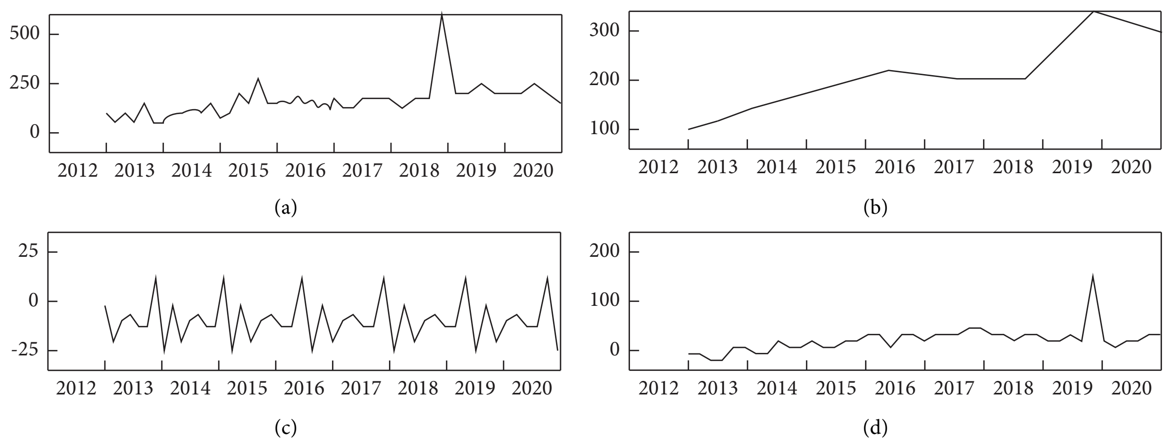

Figure 1: Time-series breakdown of a port cargo throughput.

The time-series analysis of a port cargo throughput refers to sequencing according to the generation time of a port cargo throughput data and analyzing the variation law of the port cargo throughput data. Based on this, the study provides reference for the construction of the following forecast model of a port cargo throughput [29]. Time-series analysis method is a series solution method, which combines numerical analysis, matrix theory, and many other analysis principles, and is widely used in many fields.

3.1. Time-Series Analysis of Cargo Throughput. There are many factors that affect the cargo handling capacity of the port, such as natural conditions, geographical location of the port, national regulations and policies, and economic situation. The mechanisms by which these factors work are difficult to quantify numerically, but can be fully fed back into the time series of throughput data.

In order to clearly analyze the time series of the port cargo throughput, the decomposing function is used to decompose the time series of the port cargo throughput. The throughput unit of the ordinate is 10^4 t and the abscissa is year. The exploded view is shown in Figure 1.

As shown in Figure 1, the trend components of a port cargo throughput time series are mainly divided into four categories, including long-term trend, seasonal trend, volatility trend, and irregular trend. The trend of time series of a port cargo throughput is mainly determined by the factors such as regional GDP level, economic policy, and instrument quota and shall be determined according to the actual situation [30, 31].

3.2. Design of Throughput Prediction Algorithm Based on the ES-Markov Model. The ES-Markov model [32, 33] combines the cubic exponential smoothing method with the Markov model. First, the initial prediction value is obtained by the cubic exponential smoothing method [34], and then, the state transition matrix is obtained by the Markov principle. The initial prediction value is modified to improve the prediction accuracy.

The exponential smoothing method is a special moving average method, which is characterized by assigning different weights to the previous observations, assigning larger weights to the new data, and assigning smaller weights to the old data, and the predicted values are the weighted sum of the previous observations. The exponential smoothing prediction method includes 3 methods: the first exponential smoothing method is suitable for nontrend stationary time series. the second exponential smoothing method is suitable for linear time series, and the third exponential smoothing prediction method is suitable for irregular and nonlinear time series. The cargo handling capacity of a port is influenced by the national policy, the surrounding economic development, and the natural environment, which leads to its obvious nonlinear characteristics [35–37]. Therefore, the method of exponential smoothing is used to predict the initial value. The third exponential smoothing formula is as follows:

$$\begin{cases} W_N^1 = \delta X_N + W_{N-1}^1 - \delta \cdot W_{N-1}^1, \\ W_N^2 = \delta X_N + W_{N-1}^2 - \delta \cdot W_{N-1}^2, \\ W_N^3 = \delta X_N + W_{N-1}^3 - \delta \cdot W_{N-1}^3, \end{cases} \tag{1}$$

where $N = 2, 3$, W_N^1 is the primary exponential smoothing value of the port cargo throughput in phase N, W_N^2 is the quadratic exponential smoothing value of the port cargo throughput in phase N, W_N^3 is the third exponential smoothing value of the port cargo throughput in phase N, X_N is the Nth actual data of the port cargo throughput time series, δ is the static smoothing coefficient, and $\delta \in (0, 1)$.

The predicted value of $N + m$ is as follows:

$$X_{N+m} = a + bm + cm^2, \tag{2}$$

where m is the prediction step size and the positive integers are $1, 2, 3, \ldots, n$.

The specific steps of the ES-Markov model construction are as follows.

3.2.1. Calculation Accuracy. The accuracy is the ratio of the actual value to the initial value of cubic exponential smoothing prediction, i.e.,

$$H_N = \frac{X_N}{\widehat{X_N}}. \tag{3}$$

3.2.2. Construction of State Transition Probability Matrix. The state transition probability p_{ij} is calculated as follows:

$$p_{ij} = \frac{M_{ij}}{M_i}, \quad i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, n, \tag{4}$$

where p_{ij} is the probability of objective things transferring from one state to another, M_i is the number of original data in the initial state, M_{ij} is the number of original data transferred to the original state after step k, and M_i at the end of the sample sequence is not included in the formula.

3.2.3. Determining Forecast Timing Transition Status. Markov chain has no aftereffect; that is, the occurrence of transition is only related to the current state. If the predicted object is in the initial state, only line i state vector p_{ij} of the current state transition probability matrix is considered. If the probability value of column j is the largest, the predicted object is most likely to turn to the initial state at the next moment.

Based on the above analysis results of the port cargo throughput time series, the original time series is examined, and a prediction model of the port cargo throughput is established on the basis of grey system theory [38]. The specific construction process is as follows.

In order to build a high precision throughput prediction model, the first task is to verify the original time series. Set level expression to

$$\sigma(k) = \frac{x(k-1)}{x(k)}, \tag{5}$$

where $\sigma(k)$ represents the stage ratio of x and x represents the original time series.

Then, the formula of original data time series test [39] is as follows:

$$\sigma(k) \in \left(e^{-2/n+1}, e^{2/n+1}\right), \quad k = 2, 3, \ldots, n. \tag{6}$$

If the level ratio $\sigma(k)$ of the original time series satisfies formula (6), the said time series can be considered as the design data of the throughput prediction algorithm; if the level ratio $\sigma(k)$ of the original time series does not satisfy formula (6), the level ratio of the time series can be brought into a given range by means of translation transformation. The time series after translation transformation is recorded as y, and the order ratio expression is $\varphi(k)$.

Based on the above verified original time series, the throughput prediction model is generated by accumulation to make it have strong regularity. The design process of the throughput prediction algorithm is as follows:

Set the original time series set after inspection as $X(k)$, and obtain the number series $X^{(1)}(k)$ through first order accumulation. On this basis, calculate its immediate mean series as $Z^{(1)}(k)$, and then, the throughput prediction algorithm formula is as follows:

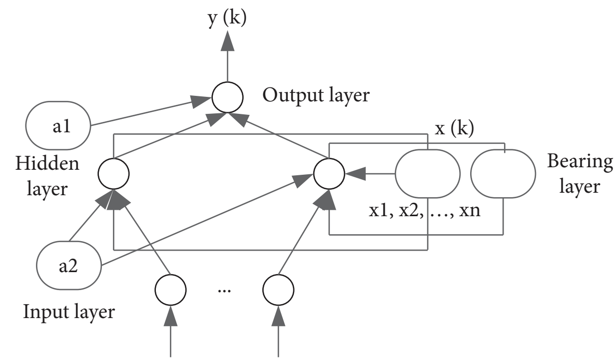

Figure 2: Elman neural network structure.

$$x^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{\mu}{a}\right)e^{-ak} + \frac{\mu}{a}, \tag{7}$$

where μ represents the endogenous control grey number, reflecting the data change relationship [12, 35, 40–42], which is determined by the time series and its adjacent mean series, and a represents the development grey number, reflecting the development trend of sequence $X^{(1)}(k)$ [43].

4. Results

4.1. Sample Data Construction Based on Elman Neural Network. Elman neural network is divided into four layers. In addition to the common input layer, hidden layer, and output layer, there is a special receiving layer. Its structure is shown in Figure 2.

It can be seen from Figure 1 that the structural connection mode of the network input layer, hidden layer, and output layer is similar to the common feedforward neural network (such as the BP neural network). Elman neural network is special in that it adds a receiving layer, which is used to remember and store the output data of the hidden layer at the previous time and return it to the network input, which enhances the ability of the neural network to process dynamic information. Referring to the structural model of Elman neural network in Figure 1, the input and output relationship is shown in equations (8) to (10)as follows:

$$x(k) = f\left[\mu^1 x_c(k) + \mu^2 x_c(k-1)\right], \tag{8}$$

$$x_c(k) = x(k-1), \tag{9}$$

$$y(k) = g\left[\mu^3 x_c(k)\right], \tag{10}$$

where y, x, μ, and x_c are output layer vector, middle layer vector, input vector, and feedback vector, respectively, μ^1 is the connection weight from the receiving layer to the hidden layer, μ^2 is the connection weight from the input layer to the hidden layer, μ^3 is the connection weight from the hidden layer to the output layer, $f(\cdot)$ is the transfer function of the hidden layer, $g(\cdot)$ is the transfer function of the output layer, and k is the current time.

According to the China Port Network, the monthly cargo throughput data of a certain port for eight months from May 2020 to December 2020 are collected and sorted

Table 1: Cargo throughput of a port in 2020/10^4 t.

Month	Throughput	Month	Throughput
1	8904	7	8892
2	7820	8	8950
3	9653	9	9320
4	8702	10	9165
5	9120	11	8730
6	9034	12	8925

Table 2: Sample data construction method.

Input sample						Output sample
2020–01	2020–02	2020–03	2020–04	2020–05	2020–06	2020–07
2020–02	2020–03	2020–04	2020–05	2020–06	2020–07	2020–08
2020–03	2020–04	2020–05	2020–06	2020–07	2020–08	2020–09
2020–04	2020–05	2020–06	2020–07	2020–08	2020–09	2020–10
2020–05	2020–06	2020–07	2020–08	2020–09	2020–10	2020–11
2020–06	2020–07	2020–08	2020–09	2020–10	2020–11	2020–12

according to the time series. In order to make full use of the data, improve the forecast precision of the port cargo throughput and serve port construction better, the sample data of Elman neural network is constructed by recursively forecasting the throughput data of the next month for 8 consecutive months; that is, there are 6 input nodes and 1 output node of the neural network. Taking the monthly cargo throughput data of a port in a city in 2020 as an example, the original data are shown in Table 1, and the construction method is shown in Table 2.

Based on the data of the port cargo throughput from May 2020 to December 2020, a set of sample data can be constructed. Among them, the latter five groups of data, namely, the cargo throughput data of a certain port from July to December 2020, are used as the test data of the neural network, and the former one is used as the training data of the neural network. At the same time, in order to ensure the fast convergence of neural network, training data and test data are normalized. Before the prediction of the port cargo throughput, according to the time characteristics of the port throughput data and many experiments, the neural network structure is determined as the input layer of 6 neurons, the output layer of 1 neuron, and the hidden layer of 7 neurons. At the same time, in network training, the hidden layer, the output layer, and the training function use tansig function, purelin function, and trainlm function, respectively, while the learning function of weights and thresholds use learngdm, which drives the term.

4.2. Analysis of Experimental Results. Elman neural network is realized by MATLAB simulation. At the same time, 69 groups of cargo throughput data of Ningbo Zhoushan port are used to complete the network training, and then, the trained network model is used to predict the cargo throughput of a port from May to December 2020, and the error is calculated by using the actual data. The port cargo throughput prediction algorithm based on the ant colony optimization proposed in [25], the port cargo throughput prediction algorithm based on SVM proposed in [26], and the proposed algorithm are used to predict the port cargo throughput, respectively.

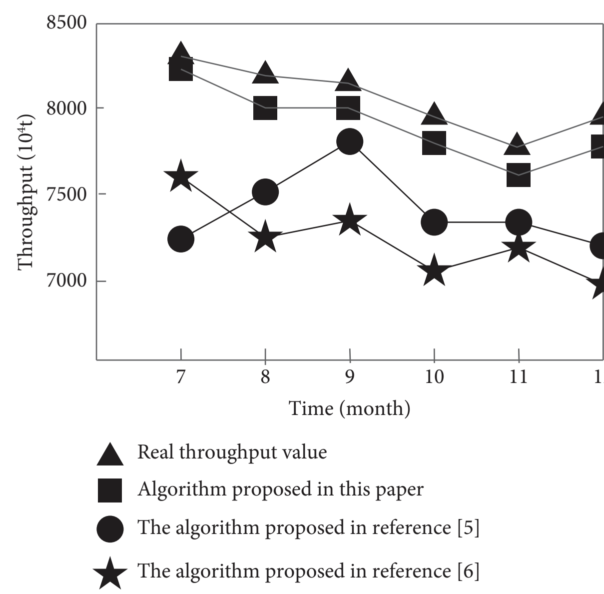

Figure 3: Predicted and actual values of different algorithms.

4.2.1. Prediction Error of Different Algorithms. The prediction results and corresponding prediction errors of the three algorithms are shown in Figures 3 and 4.

It can be seen from Figures 3 and 4 that compared with the reference algorithm, the prediction results of the port cargo throughput of the proposed algorithm are obviously closer to the actual value. At the same time, its prediction results fluctuate less, which proves that it has better stability.

4.2.2. Accuracy Test of Different Algorithms. The throughput prediction model is verified by residual test to realize the accurate prediction of the port cargo throughput. The

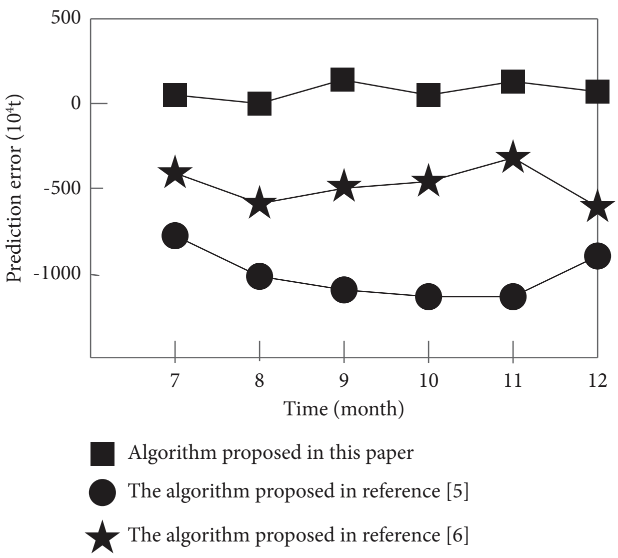

Figure 4: Prediction error of different algorithms.

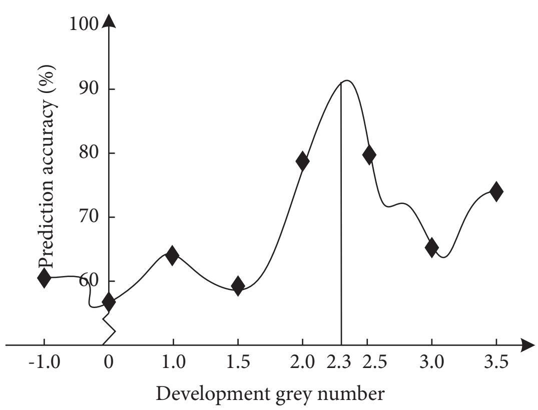

Figure 5: Development grey number change curve.

prediction effect of the cargo throughput prediction model depends on the parameter $-a$ (development grey number). According to the existing reference research, when $-a \le 0.3$ 0, the model meets the medium and long-term throughput prediction demand. When $0.3 < -a \le 0.5$, the model meets the demand of short-term throughput prediction. When $0.5 < -a \le 0.8$, the model has large error in short-term throughput prediction. When $0.8 < -a \le 1$, the accuracy of the model is poor and the residual needs to be corrected. When $-a > 1$, the prediction effect of the model is poor, so it is not recommended to apply the model.

According to the given experimental data, the optimal development grey number of the throughput prediction model is determined, and its change curve is shown in Figure 5.

As shown in Figure 5, when the development grey number is 1.8, the prediction accuracy of the model is the largest, so the best development grey number is 1.8.

According to the above description, in order to meet the prediction demand of the port cargo throughput, the development grey number range is determined as $[-0.5, +\infty]$, and the best development grey number needs to be selected according to the specific prediction demand.

Residual test refers to detecting the difference between the predicted value and the actual value of the model. The absolute residual sequence, relative parameter sequence, and average residual sequence are obtained by calculation, and the expression is as follows:

$$\begin{cases} \Delta(k) = \left[x(k) - x^{(1)}(k+1)\right], \\ \phi(k) = \left[\dfrac{\Delta(k)}{x(k)}\right]\%, \\ \overline{\phi}(k) = \dfrac{1}{n-1}\displaystyle\sum_{k=2}^{n} |\phi(k)|. \end{cases} \quad (11)$$

Based on the above experimental preparation data and the determined optimal development grey number, the throughput prediction simulation experiment is carried out to reflect the performance of the proposed method through the throughput prediction residual and accuracy. The specific experimental results and analysis process are as follows. The residual data of the cargo throughput obtained through experiments are shown in Table 3.

The division of accuracy standard is shown in Table 4.

The prediction performance of different neural networks shall be analyzed and evaluated in an all-round way by using the four evaluation indexes of the absolute percentage error maximum $\mathrm{MAX_{APE}}$, mean absolute error (MAE), average absolute percentage error (D_{MAPE}), and mean square root squared error (RMSE). Among them, the maximum absolute percentage error represents the percentage of the maximum error between the predicted value and the actual value to the actual value; the average absolute error represents the mean of the absolute value of the predicted error and reflects the accuracy; the average absolute percentage error is an indicator of the overall effectiveness of the forecasting method; the root-mean-square error reflects the dispersion of the predicted value and the actual value. The four evaluation indicators are as follows:

$$\begin{aligned} \mathrm{MAX_{APE}} &= 100\max_{i=1}^{n}\left(\left|\frac{d_f - d_i}{d_i}\right|\right), \\ P_{\mathrm{MAE}} &= \frac{1}{n}\sum_{i=1}^{n}\left|d_f - d_i\right|, \\ D_{\mathrm{MAPE}} &= \frac{100}{n}\sum_{i=1}^{n}\left|\frac{d_f - d_i}{d_i}\right|, \\ J_{\mathrm{RMSE}} &= \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(d_f - d_i\right)^2}, \end{aligned} \quad (12)$$

where d_f is the predicted value of the port cargo throughput and d_i is the actual value of the port cargo throughput.

From the evaluation results in Table 5, we can see that the prediction performance of the proposed algorithm is better than that of other two algorithms, and the performance is much better. Therefore, in the prediction of the port cargo

Table 3: Residual data of the cargo throughput.

Time	Actual value (10000 tons)	Predicted value (10000 tons)	Residual (10000 tons)	Relative residual (%)
2020–07	30.52	30.73	0.44	2.58
2020–08	35.81	32.24	−0.25	2.00
2020–09	37.36	39.21	0.74	2.07
2020–10	23.78	41.19	−0.97	2.71
2020–11	32.20	56.98	−0.36	1.04
2020–12	56.26	83.12	−0.49	1.80

Table 4: Division of accuracy standards.

Accuracy class	Describe	Numerical value
Level 1	Excellent	>95%
Level 2	Qualified	>80%
Level 3	Barely qualified	>70%
Level 4	Unqualified	≤70%

Table 5: Comparison of test indexes of different algorithms.

Evaluating indicator	Three algorithms		
	The algorithm proposed in [25]	The algorithm proposed in [26]	The algorithm proposed in this paper
MAX_{APE}	7.8	8.5	1.2
P_{MAE}	653.8	465.2	65.1
D_{MAPE}	7.1	5.6	0.9
J_{RMSE}	692.5	467.1	80.3

throughput with time characteristics, the proposed algorithm has better prediction performance and the prediction result is closer to the actual value. The experimental results show that the prediction precision of the proposed method accords with the grade 1 standard of grey system principle, which fully indicates that the proposed method has good prediction effect.

5. Conclusions and Outlook

Currently, the existing prediction algorithm of the port cargo throughput neglects the correction of the initial value of the cargo series data model, leading to a large error in the port cargo throughput prediction. So far, the port has developed to the fourth generation, whose development mode is the most efficient, namely, the supply chain mode serving the integration of trade, manufacturing industry, and logistics. Nowadays, an intelligent port aims to improve the efficiency of the port operation and management, which is also a test of port construction and management. The accurate prediction of the cargo throughput provides a basis for the planning, deployment, and reasonable allocation of tasks in advance, avoids the occurrence of a cargo backlog in the port, does not affect the delivery of goods and customer satisfaction, and fully improves the operating efficiency of the port, forming a virtuous circle. Therefore, accurate and reasonable forecast of the port cargo throughput is very important for port layout and even transformation and upgrading. As a result, we designed a prediction algorithm of the port cargo throughput based on the ES-Markov model. The ES-Markov model is constructed to modify the initial predicted value of the sample data. Based on the final results of the time-series arrangement and ES-Markov model, the port cargo throughput prediction algorithm is designed. The experimental results show that compared with the reference algorithm, the error of the prediction result of the port cargo throughput of the proposed algorithm is smaller and the prediction result is more stable, indicating that the application performance of the proposed algorithm is better. Besides, the experimental findings indicate that the prediction precision of the proposed method accords with the grade 1 standard of grey system principle, which fully indicates that the proposed method has good prediction effect.

Data Availability

No data were used to support the findings of the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Evaluation of the Mechanical Failure Criterion to Consider the Triple Base Propellant Safety Life: Application of Sustainable Renewables for Environmental Hazards

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Implementation of clean energy and renewables is essential for the consideration of environmental impact because it can be implemented in supply chain networks and sustainable management procedures for safety. In order to study the safety life failure criterion of a triple base propellant under the failure mode of mechanical properties, an accelerated aging test, an evaluation method for the launch safety test of gun propellant charge, and a compressive strength test were used. The failure criterion of mechanical properties was obtained by researching the correlation between launch safety change and mechanical property change of samples. Berthelot's equation was used to predict the safety life of the triple base propellant. The results show that the mechanical failure criterion is "27% reduction of maximum compressive strength." The safety life at 25°C and 75% humidity is 13.77 years.

1. Introduction

As the power source of ammunition, the performance of the propellant directly affects the operational efficiency of the ammunition system [1–6]. With the rapid development of military technology, the speed of equipment upgrading is increasing faster and faster, and new propellants are emerging indefinitely [7–11]. The triple base propellant is a kind of high-energy propellant, which is widely used in large caliber ammunition systems [12–16]. Compared with the traditional propellant, its composition is more complex [17–21]. The use of new materials and new technologies leads to the degradation law and mechanism of the propellant in the long-term storage process, which is significantly different from the traditional propellant [22–27]. Triple base propellants have the characteristics of high energy, high burning rate, and low burning temperature because of the addition of nitramine azide as an energetic plasticizer [28, 29]. Due to the complex composition and variety of influencing factors in the process of storage and use, there are few research studies on its safety life [30–33] and mainly focus on the change of the content of stabilizers during storage [34–37]. Accidents such as early explosion or chamber explosion occur in the use of a triple base propellant, which is still in the safe life range [38–41]. This indicates that the safety life assessment of a triple base propellant based on the content of the stabilizer is defective. If the mechanical failure criterion can be determined by some method, the accuracy and efficiency of the triple base propellant life assessment will be greatly improved.

The triple base propellant was mainly affected by the mechanical environment of the chamber in the process of use. Due to the high-speed and high-pressure combustion gas in the chamber, propellant particles will be squeezed and

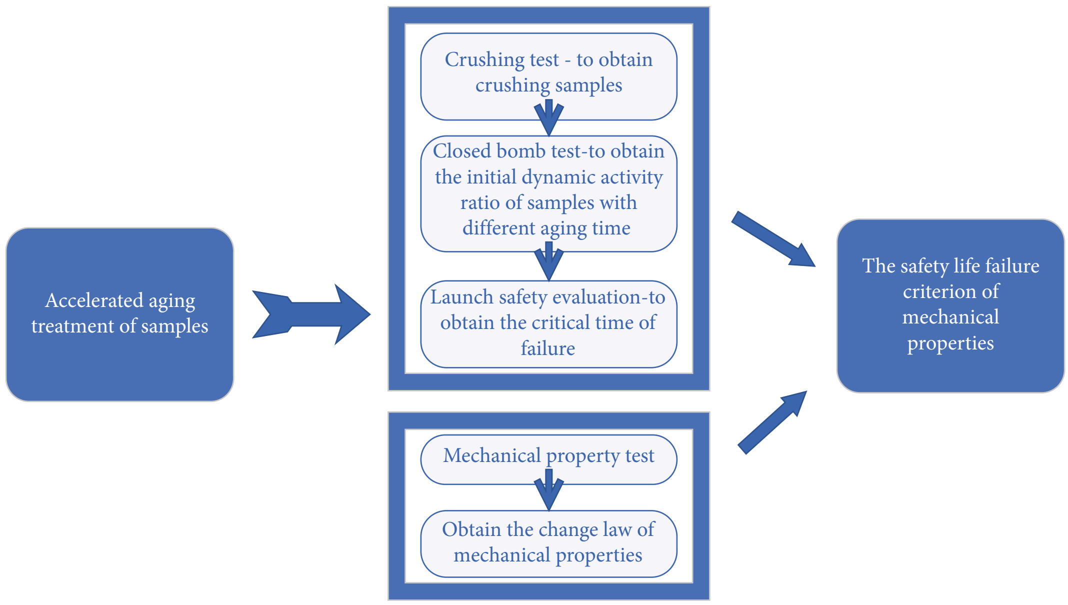

Figure 1: Flowchart of the experimental scheme.

collide with each other during the launching process, and they will also be strongly impacted by the bottom and wall of the shell. Many fragmentations are made when the mechanical conditions of propellant particles cannot meet the requirements of the strong load in the chamber, which will lead to a sharp increase in the burning surface and the gas generation rate of the propellant. This can lead to a sudden increase in local pressure in the chamber and eventually lead to premature explosion or even chamber explosion [42, 43]. Therefore, the mechanical properties of triple base propellants are the key factors affecting the safe use of samples after long-term storage. Research shows that the change of mechanical properties is the main feature of the storage process of triple base propellants, and tracking the change of mechanical properties can directly reflect the performance of triple base propellants. But due to the lack of failure criteria, the life evaluation parameters cannot be obtained directly according to the data of mechanical properties [44].

The dynamic process of propellants in the process of launching can be simulated by the “evaluation method for launch safety test of gun propellant charge” [45], which accurately judges whether the sample meets the safety requirements for launching. However, the aging life of samples cannot be obtained quickly because of the large number of test samples and long test cycles. Based on the respective characteristics of the mechanical performance test of triple base propellants and the launch safety test of propellants, whether the two can be combined to obtain the mechanical failure criterion of triple base propellants and establish the mechanical aging life evaluation method of triple base propellants is of great significance to solve the safety life problem of triple base propellants in the service process.

In this study, the mechanical test and the launch safety test were carried out to explore the correlation between static mechanical property and launch safety. The obtained mechanical property change data are correlated with the launch safety test data to obtain the mechanical property failure critical point of triple base propellants. The aging life equation of propellants under a mechanical failure mode was established, and the safety life of triple base propellants is estimated based on the determined failure criterion.

2. Experimental

2.1. Experimental Scheme. The experimental scheme is shown in Figure 1.

2.2. Accelerated Aging Test. In order to shorten the test period, the samples of triple base propellants with different aging degrees were obtained by an accelerated aging test. The accelerated aging test conditions refer to the national military standard GJB 770B-05 [46].

Aging temperature is as follows: 51°C, 61°C, and 71°C.

Aging humidity is as follows: 75% (annual average humidity of the test site).

2.3. Mechanical Property Test. The precision universal material testing machine was used to test the compressive strength according to “method 415.1”, GJB770B-05.

2.4. Launch Safety Test. The launch safety test can reproduce the combustion and mechanical environment in the propellant chamber, simulate the extrusion crushing dynamic process of the propellant charge in the launching environment according to the chamber explosion mechanism of the propellant charge, and finally establish the quantitative relationship between the extrusion stress of the propellant and the crushing degree in the corresponding launching environment [47].

Table 1: The calibration data of the test device.

	Maximum bottom pressure/MPa	Initial velocity of projectile/ $m \cdot s^{-1}$
Simulation	331.0	929.6
Test	327.4	931.0
Error*	1.1%	0.16%

*Error value = |(Simulation value) − (Test value)/Simulation value × 100%|.

(a) (b) (c)

Figure 2: Broken samples of different aging times under the same pressure; (a) samples without storage; (b) samples aged for 15 days; (c) samples aged for 30 days.

2.4.1. Evaluation Process

(1) The [48–50] extrusion crushing process of projectile bottom propellant charge during gun launching is simulated by the extrusion crushing simulation test device of propellant charge, and the broken propellant bed of propellant charge under the extrusion stress of projectile bottom propellant charge is obtained.

(2) The dynamic activity test of the broken propellant bed is carried out by using the dynamic activity test system of propellant charge, and the dynamic activity curve and the initial dynamic activity ratio of the projectile bottom broken propellant bed under real launch conditions and mechanical environment are determined.

(3) The critical initial activity ratio is determined according to the extrusion stress of the projectile bottom in the actual launching of the propellant, which is used as the evaluation standard.

3. Analysis of Test Results

3.1. Results of the Launch Safety Test. After the accelerated aging test, the broken propellant in the real mechanical environment is obtained by using the overload simulation loading device. The initial dynamic activity ratio of the broken propellant with different aging times was obtained by the initial dynamic activity ratio test. The calibration data of the test device are shown in Table 1.

The errors between the simulated parameters of the test device and the actual launch environment parameters meet the test requirements after correction.

3.1.1. Results of the Crushing Test. In order to obtain the relationship between the initial dynamic activity ratio and aging time of samples, it is necessary to conduct dynamic activity ratio tests on broken samples with different aging times and different test pressures. The first step of the whole experiment is to obtain samples with different degrees of fragmentation. The broken samples with different aging times are obtained by using the overload simulation loading device. The test results are shown in Figure 2, Tables 2–4.

Table 2: Test data of propellant fragmentation without storage.

No.	Weight/ g	Maximum extrusion stress of the propellant bed/ MPa
1	198.5	7.20
2	198.5	10.59
3	201.5	15.63

Table 3: Fragmentation test data of propellant samples aged for 15 days.

No.	Weight/ g	Maximum extrusion stress of the propellant bed/ MPa
1	199.5	5.97
2	203.5	9.12
3	203.0	14.38

Table 4: Fragmentation test data of propellant samples aged for 30 days.

No.	Weight/ g	Maximum extrusion stress of the propellant bed/ MPa
1	202.5	7.843
2	203.5	10.28
3	202.5	15.36

From the test results, it can be seen that the crushing degree of samples with the same aging time increases with the maximum pressure of the simulated device bed. The crushing degree of samples increases with aging time. This shows that the mechanical properties of the samples are decreased after aging.

3.1.2. Dynamic Activity Ratio Test. The P-t curve shows the change of pressure in the test equipment with time and can

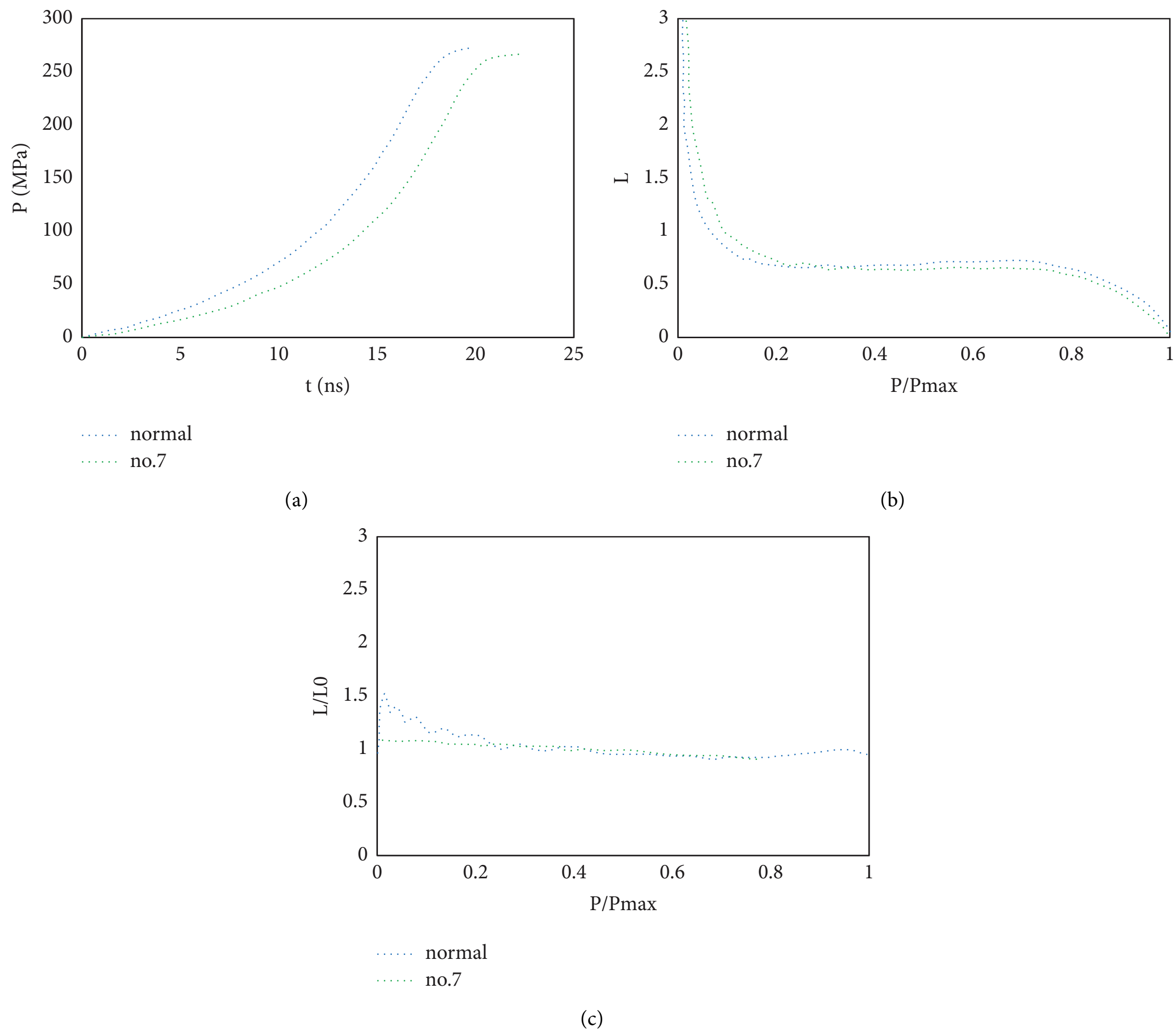

FIGURE 3: P-t curves, dynamic activity curves, and dynamic activity ratio curves of propellants. (a) P-t curves, (b) dynamic activity curves, and (c) dynamic activity ratio curves.

TABLE 5: Test data of the initial dynamic activity ratio of samples without storage.

No.	Weight/g	Maximum extrusion stress of the propellant bed/MPa	Initial dynamic activity ratio/R_0
1	198.5	7.20	1.024
2	198.5	10.59	1.084
3	201.5	15.63	1.108

TABLE 6: Test data of the initial dynamic activity ratio of samples aged for 15 days.

No.	Weight/g	Maximum extrusion stress of the propellant bed/MPa	Initial dynamic activity ratio/R_0
1	199.5	5.97	1.198
2	203.5	9.12	1.259
3	203.0	14.38	1.519

reflect the acceleration of the initial combustion rate and the gas production rate caused by the increase of the combustion surface after the sample is broken. The dynamic activity curve can be further obtained through the P-t curve, and the initial dynamic activity ratio data and curves are obtained as shown in Figure 3.

The test data of different samples are shown in Table 5, Table 6, and Table 7.

Composed the diagram from the test data.

Figure 4 shows that the dynamic initial activity ratio increases with the increase of the maximum bed pressure at the same aging time. The longer the aging time of the sample, the

Table 7: Test data of the initial dynamic activity ratio of samples aged for 30 days.

No.	Weight/g	Maximum extrusion stress of the propellant bed/MPa	Initial dynamic activity ratio/R_0
1	202.5	7.843	1.374
2	203.5	10.28	1.427
3	202.5	15.36	1.661

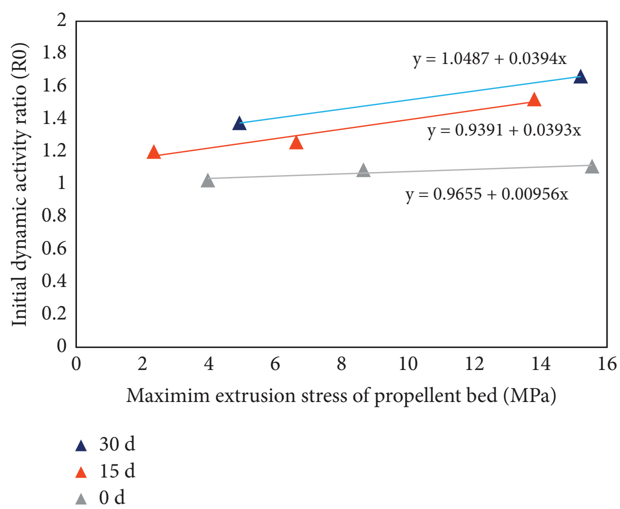

Figure 4: The initial dynamic activity ratio of samples with different aging times.

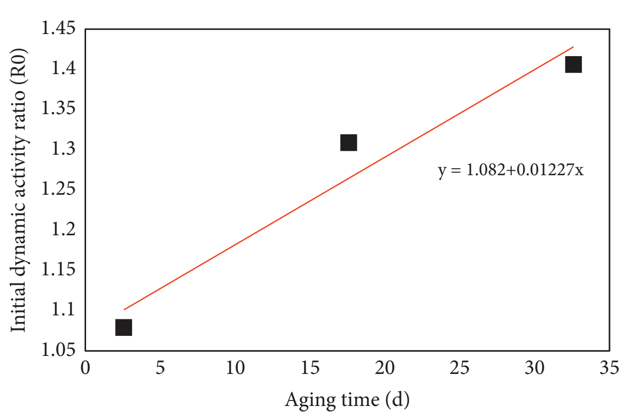

Figure 5: Dynamic initial activity ratio-aging time curve.

greater the fragmentation, and the greater the dynamic initial activity ratio, the higher the maximum bed pressure. The test results show that the maximum pressure of a gun barrel is 9.58 Mpa, and the corresponding dynamic initial activity ratios of propellant samples with different aging times are 1.057, 1.316, and 1.425, respectively. According to the data, we make a curve of dynamic initial activity ratio aging times, as shown in Figure 5.

According to the "evaluation method for the launch safety test of gun propellant charge," when $R_0 < 1.3$, the samples are safe to launch. From the fitting equation "$y = 1.082 + 0.01227x$ ($R^2 = 96\%$)," when $y = 1.3$, $x = 17.76$. In other words, when accelerated at 71°C for 17 days, the launch safety reaches the critical point.

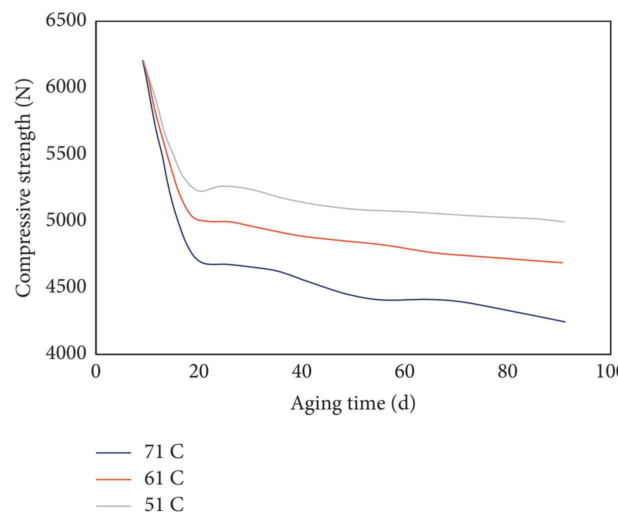

Figure 6: Change curves of compressive strength with aging time.

3.2. Compressive Strength Test. In this study, the maximum compressive strength of the samples was obtained by measuring the propellant samples with different aging times. Taking $F = 6200$ N as the starting point (average compressive strength of the nonaged sample at room temperature), according to the original data, the curves of compressive strength with aging time were obtained, as shown in Figure 6.

It can be seen from Figure 6 that the compressive strength of propellant samples decreases with the increase of aging time at different aging temperatures; at the same aging temperature, the greater the humidity is, the faster the compressive strength decreases. This may be due to the degradation and chain breakage of polymers such as nitrocellulose. The grid structure formed by nitrocellulose is damaged, and the overall mechanical strength is reduced [51, 52]. In addition, in an environment of high humidity and high temperature, the droplets condensed on the surface of the pillar will dissolve some components such as nitroguanidine, and the greater the humidity, the greater the dissolution. This will result in loosening of the overall structure of the propellant column and formation of ravines and holes on the surface, weakening the integrity of the overall structure of the propellant. Furthermore, under the action of stress, the surface layer structure is easy to deform, resulting in a decrease in the overall compressive strength.

3.3. Mechanical Life Evaluation Equation. MATLAB software was used to fit the compressive strength of samples at different aging temperatures. First, we define the values of x and y, i.e., $x = t(\ldots)$ and $y = F(\ldots)$ and then output the curve. We select the classical equation in the function library to

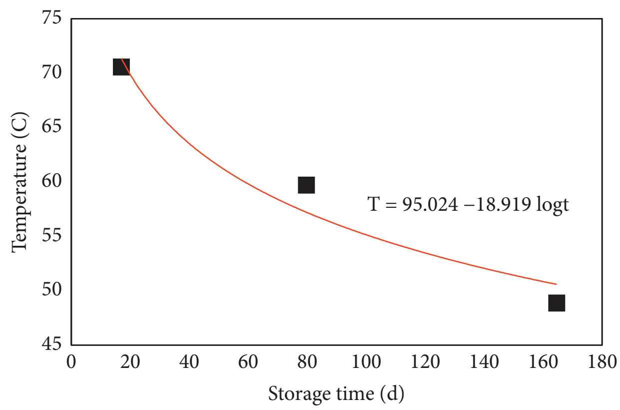

Figure 7: Life fitting curve.

Table 8: Aging time to failure critical point under different aging conditions.

Aging temperature/T	51°C (d)	61°C (d)	71°C (d)
Aging time/t	174	84	17

The life evaluation equation is obtained by using the Berthelot equation of fit.

simulate the curve, and the following equation can be obtained.

$T = 51°C$:

$$F = 5173 \times \exp(-0.0007781t)\left(R^2 = 96\%\right), \quad (1)$$

$T = 61°C$:

$$F = 4930 \times \exp(-0.001041t)\left(R^2 = 96\%\right), \quad (2)$$

$T = 71°C$:

$$F = 4650 \times \exp(-0.001704t)\left(R^2 = 95\%\right). \quad (3)$$

F is the maximum compressive strength, N; t is the storage time, d.

It can be seen from the launch safety test that the sample reaches the critical point of launch safety after 17 days of aging under the conditions of the 71°C accelerated aging test. When $t = 17$ is taken into (2), $F = 4517$N. The decrease degree of the maximum compressive strength can be determined by $\alpha = (1\text{-}F/6200) \times 100\%$, and then $\alpha = 27.15\% \approx 27\%$. Under the accelerated aging test condition, when the maximum compressive strength of the sample decreases by 27%, the critical point of launch safety is reached, which is the mechanical failure criterion. According to formula (1–3), the aging time of samples reaching the critical point of failure under accelerated aging test conditions at different temperatures can be obtained based on the criterion of 27% reduction of maximum compressive strength, as shown in figure 7, Table 8.

$$(T = 95.024 - 18.919 \log t)\left(R^2 = 96\%\right). \quad (4)$$

T is the aging temperature, °C; t is the storage time, d.

According to the mechanical failure criterion "the maximum compressive strength decreases by 27%," and the life of the triple base propellant is evaluated. According to (4), when $t = 25°C$, the storage time is 5026 days, that is, the safe life of the triple base propellant is 13.77 years at room temperature (25°C).

4. Discussion and Conclusion

4.1. Discussion. This study shows the correlation between mechanical properties and launch safety. The combination of the two test methods has solved the problem that the triple base propellant lacks the mechanical failure criterion and cannot be evaluated from the perspective of mechanical properties.

The test results of propellant launching safety show that under the same chamber mechanical environment, the extension of aging time will lead to the increase of triple base propellant fragmentation, the sudden increase of the combustion surface, the acceleration of the initial burning rate, the acceleration of local pressure, and the increase of the dynamic initial activity ratio. The mechanical test shows that the maximum compressive strength of the triple base propellant decreases with aging time; at the same aging time, the higher the aging temperature is, the faster the maximum compressive strength decreases.

The change laws of these experimental phenomena are related. Combined with the data of the 71°C accelerated aging test and the results of the propellant launching safety test, the mechanical failure criterion of the triple base propellant is calculated as "the maximum compressive strength decreases by 27%." Of course, this result may not be accurate and specific, but this method to determine the mechanical failure criterion of the propellant is feasible. In the follow-up study, more accurate and instructive life evaluation results can be obtained by increasing the number of tests and reducing the error.

4.2. Conclusion. The method of combining launching safety tests with mechanical property tests solves the problem that it is difficult to determine the mechanical failure criterion of triple base propellants and provides a strong basis for the establishment of a life evaluation system for such propellants.

(1) The relationship between the aging time and initial dynamic activity ratio in the process of accelerated aging of triple base propellants at 71°C can be expressed by the equation: $y = 1.082 + 0.01227x$ ($R2 = 94\%$). When the dynamic initial activity ratio is 1.3, the aging time is about 17 days.

(2) The mechanical failure criterion of the triple base propellant is calculated as "the maximum compressive strength decreases by 27%." According to the Berthelot equation, the safety life of the triple base propellant at room temperature (25°C) is 13.77 years.

Abbreviations

R_0: Initial dynamic activity ratio
T: Accelerated aging test temperature/°C
F: Maximum compressive strength/N
T: Storage time/days
α: Degradation degree of mechanical properties
R^2: Goodness of fit
P-t: Relationship between pressure and time during the test
L: The value of the dynamic activity
P_{max}: Maximum pressure that the sample can reach during the test/Mpa.

Data Availability

No data were used to support the findings of this study.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Article

Pricing Decisions in Dual-Channel Supply Chain considering Different Fairness Preferences and Low-Carbon Advertising Level

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Countries around the world advocate low-carbon, green, and environmentally friendly lifestyles to combat climate change, which provides clear direction for enterprise decisions. This paper studies a low-carbon dual-channel supply chain based on behavioral economics, incentive theory, and optimization models to better formulate pricing decisions. This paper constructs a fair and neutral decentralized decision-making model (FNDD), a decentralized decision-making model considering Nash bargaining fairness concerns (NBFDD), a decentralized decision-making model considering absolute fairness concerns (AFDD), and a fair and neutral centralized decision-making model (FNCD) considering consumer preferences and the situations where supply chain members are fairness concerns or fairness neutrality. This paper analyzes the effect of low-carbon advertising level on pricing strategies of online retailers and offline stores and compares pricing strategies of online retailers and offline stores in four decisions. The results show that Nash bargaining fairness concerns of supply chain members could effectively reduce the retail price of low-carbon products and increase their sales volumes. Absolute fairness concerns intensify the dual marginal effect of decentralized decision-making.

1. Introduction

For businesses, pricing decisions of products affect their normal operations and development. In recent years, the low-carbon supply chain has developed rapidly, and online and offline consumption systems blend with the rise of electronic commerce. Many manufacturing enterprises such as P & G, Unilever, and GM have opened online sales channels based on original offline channels. In dual-channel supply chain, developing appropriate online and offline retail prices to promote the long-term development of the supply chain has become an important issue facing enterprises.

Companies' carbon emission reduction significantly impacts pricing decisions under the background of "double carbon." In recent years, the world climate has faced severe problems which have endangered the living environment, health, and safety of humankind. In the face of global climate change, countries urgently need to work together to reduce or control carbon dioxide emissions [1]. The United Nations Climate Change Conference produced the "Bali Roadmap" and established a clear agenda for negotiations on climate change on December 15, 2007 [2]. The European Union plans to achieve a 40 percent reduction in carbon emissions by 2030 compared with 1990. In September 2020, the Chinese government proposed reducing carbon dioxide intensity by more than 65% by 2030 compared with 2005 and achieving carbon neutrality by 2060 [3]. In order to fulfill the responsibility and obligation of low-carbon, countries worldwide have issued relevant policies to promote the sustainable development of the low-carbon economy. The concept of sustainable development in the era of the low-carbon economy guides the formation of consumers' awareness of low-carbon consumption [4].

Consumers' purchase behavior decisions consider not only the price factors but also the low-carbon factors in the process of products and services. The price and carbon emissions of low-carbon products will become the essential parts of consumer behavior decision-making, the important parts of enterprises to determine customer value needs, and the careful consideration of consumer behavior.

A group of behavioral scientists represented by Kahneman have revealed that people pay great attention to fairness in practical problems through many empirical studies. Supply chain participants should pay attention to the maximization of their interests and the fairness of income distribution in supply chain system. Therefore, we should consider the impact of supply chain members' fairness concerns on pricing decisions in low-carbon dual-channel supply chain.

Previous studies mainly focused on the impact of fairness concerns behavior of single-channel supply chain members on their decision-making. The research objects of this paper are a single supplier, a single online retailer, and a single offline store. We construct the FNDD, NBFDD, AFDD, and FNCD models considering the fairness concerns behavior of supply chain members. Meanwhile, we analyze the effect of low-carbon advertising level on pricing strategies of online retailers and offline stores and compare pricing strategies of online retailers and offline stores in four decisions. Besides, the effects of different reference points are tested in this paper. This will help understand the impact of fairness preferences on enterprises' decision-making and mechanism changes.

On the one hand, considering supply chain members' contribution differences and consumer preferences, the Nash bargaining solution is used as a fair reference point to describe supply chain members in computation. The pricing strategies considering Nash bargaining fairness concerns are studied, which is more realistic. On the other hand, we explore the impact of absolute fairness concerns behavior on pricing strategies of dual-channel supply chain members. By comparing and analyzing the difference in the impacts of Nash bargaining fairness concerns and absolute fairness concerns on supply chain members' pricing strategies, we can seek an appropriate reference point for the fairness concerns of supply chain members. In addition, this paper lays a theoretical foundation for enterprises to achieve the "double carbon" goal and help them complete the carbon emission reduction goal. The main issue discussed in this paper is the impact of Nash bargaining fairness concerns behavior and absolute fairness concerns behavior on supply chain members' decision-making, that is, how to choose partners under different fairness preferences.

The rest of the article is organized as follows. In Section 2, we review the literature relevant to this article. In Section 3, we construct four important decision models. We compare and analyze retail prices, sales volumes, and profits of online retailers and offline stores under four decision models and examine the impact of different reference points in Section 4 and Section 5. We provide our conclusions and managerial insights in Section 6.

2. Literature Review

This section reviews the related literature in two main streams: (1) pricing strategies of low-carbon supply chain and (2) fairness preference of supply chain members. Afterward, the research gaps and contributions of the current study are addressed.

2.1. Pricing Strategies of Low-Carbon Supply Chain

2.1.1. Single-Channel Low-Carbon Supply Chain. Many scholars have built low-carbon supply chains to study their pricing strategies but have not considered the impact of fairness concerns. Li et al. simulate the government's subsidy policy for low-carbon enterprises and retailers using game theory and show that the government subsidy strategy based on carbon emission reduction level can effectively drive low-carbon enterprises to further reduce carbon emissions [5]. Wei and Wang use the differential game method to study the interactive relationship between carbon emission reduction technology innovation and government intervention under decentralized decision-making and centralized decision-making. The research found that the optimal level of carbon emission reduction technology innovation under decentralized decision-making is same as that under centralized decision-making without cost-sharing [6]. Zhang et al. analyze the optimal strategy of low-carbon technology innovation in the context of government subsidies. The research found that when consumers' low-carbon preference is weak, retail prices of products are negatively correlated with subsidies [7]. The above scholars have built a single-channel low-carbon supply chain to study its pricing strategies but have not considered the condition of the dual-channel supply chain.

2.1.2. Dual-Channel Low-Carbon Supply Chain. Building dual-channel low-carbon supply chains to study supply chain decision-making problems is gradually increasing. Che et al. construct a dual-channel supply chain model and study the impact of the manufacturer's participation in carbon trading and green financial loans on the participant's profits and emission reduction decisions using the Stackelberg game. The results show that the carbon emission reduction level of the manufacturer is inversely proportional to the relevant price, and the demand and profit of two channels are proportional to the emission reduction amount under carbon trading mechanism [8]. Santanu et al. analyze a dual-channel supply chain model considering the emission-sensitive random demand under compulsory government quota, transaction supervision, and consumers' low-carbon preference. The results show that the decentralized dual-channel supply chain can be effectively coordinated and adopting a repurchase contract and emission reduction cost-sharing contract can be a win-win situation for supply chain members under emission-sensitive random demand [9]. The influence of external factors on supply chain members' pricing decisions is explored. Few scholars explore the impact of internal factors such as the behavior of supply chain members on the pricing decisions.

2.2. Fairness Preference of Supply Chain Members. Different scholars have different research angles on the fairness of supply chain members. Li et al. construct a government incentive model for corporate carbon emission reduction and study the impact of corporate equity preference on the government's carbon emission reduction incentive strategy considering the multiobjective nature of corporate carbon emission reduction and enterprises' fairness preference. The research shows that the degree of enterprises' fairness preference directly affects enterprise effort [10]. Lu et al. establish an income distribution model considering the unfair aversion to functional logistics service providers (FLSP). The results show that the degree of unfair aversion to FLSP is negatively correlated with the proportion of income distribution [11]. Liu et al. discuss the impact of retailers' fairness on cooperative relationships in sustainable supply chains and reveal that retailers' fairness issues affect members' decision-making and cooperation in sustainable supply chain management [12]. Zhang et al. study a dual-channel supply chain consisting of a manufacturer and a retailer, where the retailer exhibits vertical and horizontal fairness concern, and reveal that the fairness concern behavior of the retailer only affects wholesale prices and online channel strategies [13].

2.2.1. Retailers' Fairness Concerns. Some scholars explore supply chain members' decision-making problems when retailers have fairness concerns. Sarkar and Bhala solved the apparent conflict between fairness and efficiency in closed-loop supply chains (CLSCs) and found that decentralized channels are effective when retailers strongly oppose disadvantageous inequality (DI) and advantageous inequality (AI) [14]. Zhou et al. study manufacturers' optimal decision-making in supply chain considering retailers' fairness behavior when demand information is asymmetric. The results show that retailers' fairness behavior and products' green degree will encourage the manufacturer to change its contract design strategy [15]. Rikuo et al. analyze a two-echelon supply chain considering the retailer's fairness concerns. The research shows that channels can be successfully coordinated in a balanced state [16]. Wang and Matsubayashi design three closed-loop supply chain models. The results show that manufacturers' corporate social responsibility behavior can effectively reduce retailers' fairness concerns behavior, but it will reduce the efficiency of government subsidies to a certain extent [17]. Zheng et al. incorporate retailers' fairness concerns into the coordination of three closed-loop supply chain (CLSC) members. The research found that different coordination mechanisms have different benefits for three CLSC members [18]. Fei and Gao study a two-stage green supply chain and compare the optimal pricing strategies under each mode. The research shows that the introduction of revenue sharing contract can effectively improve the profit of supply chain members under decentralized decision-making so that manufacturers and retailers can achieve Pareto improvement at the same time [19]. These scholars only study the impact of retailers' fairness concerns on supply chain decision-making and do not consider suppliers' fairness concerns.

Some scholars consider the impact of low-carbon advertising level and retailer fairness issues on pricing decisions. Zhang et al. study a two-echelon supply chain consisting of an advertising retailer and a consumer with environmental awareness and analyze the impact of consumer environmental awareness, the proportion of retailers sharing low-carbon costs, and the fairness concerns coefficient on supply chain enterprises. The research found that member's fair attention coefficient is negatively correlated with wholesale prices and retail prices of carbon emissions regardless of whether the retailer undertakes carbon emission reduction costs [20]. Yu et al. analyze the impact of emission reduction cost coefficient, low-carbon product advertising effort cost coefficient, and low-carbon product advertising effort cost allocation ratio on the profit of dual-channel supply chain. The research shows that retailers can use their advantages to get closer to consumers and improve the efficiency and pertinence of advertising in retail channels [21]. Zhou et al. study a low-carbon supply chain channel consisting of a manufacturer and a retailer and show how contract design can optimize low-carbon supply chain management decisions and improve supply chain performance. The research found that, regardless of whether the retailer has fairness concerns, cooperative advertising contracts cannot achieve channel synergy but can improve channel effectiveness [22]. The scholars only explore the impact of retailers' fairness concerns on pricing strategy and do not study suppliers' fairness concerns.

2.2.2. Suppliers' Fairness Concerns. Some scholars have also explored the impact of suppliers' fairness concerns on supply chain members' decisions. Wang et al. construct an online supply chain and study the optimal decisions in three cases: decentralized decision-making model without considering manufacturer fairness, decentralized decision-making model considering the manufacturer's fairness, and centralized decision-making model. Research shows that the manufacturer's fairness reduces system efficiency [23]. Jian et al. constructed a Stackelberg game model considering the fairness of the manufacturer's centralized decision-making and decentralized decision-making to study pricing decisions of products and found that when the manufacturer has fairness concerns behavior, it is not conducive to the environmental performance of green products resulting in waste of resources and forcing retailers to reduce sales and improve retail prices of products [24]. Jian et al. construct a centralized and decentralized decision-making model considering manufacturers' fairness concerns behavior to study pricing decisions of products. The results show that suppliers' fairness concerns behavior is not conducive to the environmental performance of green products [25]. Han et al. study the decision-making behavior in a low-carbon online supply chain when the supplier obtains government carbon subsidies and has fairness concerns behavior. The results show that consumers' preference for low-carbon products is beneficial to supply chain operation [26]. Wang et al. consider the fairness concerns behavior of online retailers and construct three online closed-loop supply chain decision models. The research found that the cost-sharing contract can maximize the system profit [27]. Zou et al.

Table 1: Literature review.

	Retailers have fairness concerns	Manufacturers have fairness concerns	Pricing decisions of dual-channel supply chain	Pricing decisions of dual-channel supply chain based on different fairness references
Zhang et al. [20]	√			
Jian et al. [24]		√		
Zou et al. [28]		√		
Bo et al. [29]	√	√		
Guan et al. [30]	√	√		
Ye et al. [31]	√	√		
Che et al. [8]			√	
Santanu et al. [9]			√	
Li et al.[32]		√	√	
This paper	√	√	√	√

discuss the impact of equity on sustainable low-carbon supply chain under carbon quota policy. The results show that the profit of centralized low-carbon supply chain (LCSC) is higher than that of decentralized LCSC [28]. These scholars only study the impact of suppliers' fairness concerns on supply chain decision-making and do not consider retailers' fairness concerns.

2.2.3. All Supply Chain Members Have Fairness Concerns. Many scholars have studied the optimal decisions considering the fairness concerns behavior of supply chain members. Bo et al. study the decision-making of the supply chain of fresh agricultural products considering fairness behavior. The research found that the profits of all parties under the revenue-sharing contract are more efficient [29]. Guan et al. study supply chain coordination between upstream manufacturers and downstream retailers. The results show that prominent channel members are more sensitive to fairness [30]. The members' fairness concerns behavior considering low-carbon advertising level has not been studied. Ye et al. construct a fair utility system based on Nash bargaining theory and discuss the retailer's advertising strategy under decentralized decision-making, the manufacturer's emission reduction strategy, and related strategies under centralized decision-making. The research found that the supplier's fairness concern behavior is not conducive to the development of a low-carbon economy. In contrast, the retailer's appropriate attention to fairness is conducive to the development of a low-carbon economy [31]. No scholars explored the impact of fairness concerns on supply chain pricing strategies under different fairness references.

2.3. Research Gaps and Contributions. The literature review is shown in Table 1. According to Table 1, the research gaps and contributions of this article are as follows.

Currently, most of the studies on fairness concerns behavior are aimed at a single member with fairness concerns behavior while other members are fair and neutral (e.g., [20, 24, 28]). Few scholars consider that all members have fairness concerns (e.g., [29–31]).

In addition, the research on supply chain pricing strategies is mainly for single-channel supply chains (e.g., [30, 31]), and few scholars have studied those of dual-channel supply chain members (e.g., [8, 9]). Besides, few scholars have considered the impact of fairness concerns on pricing strategies of supply chain members under different reference points (e.g., [32]).

Based on previous studies, this paper explores the impact of supply chain members' fairness concerns on the pricing strategy of dual-channel supply chain under different fairness reference points. Besides, this paper considers that all members have fairness concerns. We expect to obtain an optimal strategy to formulate the optimal pricing strategies in low-carbon supply chain.

In the existing research, the literature works that are highly related to this paper are [22, 32–34], where Hosseini-Motlagh et al. [33] make contributions to the literature on SC coordination by proposing a novel model for coordinating sustainable supply chain (SSC) under competition, supposing a manufacturer invests in reducing the carbon emissions and two retailers compete on investing in the green effort and they do not consider supply chain pricing decisions. In contrast, this paper considers the pricing decisions in supply chain. Hosseini-Motlagh et al. [34] develop a reverse supply chain model that derives optimal pricing, sustainability level, and corporate social responsibility decisions under demand disruptions. We focus on the impact of fairness concerns on pricing decisions in supply chain under different reference points in this paper. Li et al. [32] consider the case in which the manufacturer has fairness concerns behavior, but the retailer does not have. They suppose the manufacturer and the retailer adopt a cooperative advertising strategy to boost sales. This paper analyzes the impact of different fairness reference points on pricing strategies of supply chain members considering all members have fairness concerns behavior. Zhou et al. [22] consider a low-carbon single-channel supply chain consisting of a manufacturer and retailer and show how to optimize the low-carbon supply chain management decision and improve the supply chain performance through contract design, and we study pricing strategies of dual-channel supply chain members in this paper.

3. Pricing Strategies Model of Dual-Channel Supply Chain Based on Different Fairness Reference Points and Low-Carbon Advertising Level

We explore a dual channel composed of a single supplier, a single online retailer, and a single offline store, as shown in Figure 1. The paper considers a dual-channel supply chain, and low-carbon factor is an important factor to be considered in competition. We assume that the market supply and demand balance. Consumers can buy products without differences online and offline. The wholesale prices of the dual-channel retailers are the same. In order to maximize the promotion of low-carbon products, it is very necessary for retailers to carry out corresponding advertising in low-carbon supply chain. Although this will further increase products' cost, the increase of products' sales brought by advertising will lead to increase in corporate profits. In this paper, the low-carbon efforts of retailers refer to the low-carbon supply chain in which retailers promote low-carbon products and increase the sales of low-carbon products. Online retailers have low-carbon advertising costs $1/2l_1^2$, showing the advertising effort that retailers are investing in low-carbon products. Offline stores have low-carbon advertising costs $1/2l_2^2$. Referring to the basic framework of demand function in literature [35], this paper designs the demand functions of online retailers and offline stores as follows:

$$\sigma_1 = a\sigma - \beta P_1 + \gamma(l_1 - l_2), \tag{1}$$

$$\sigma_2 = (1-a)\sigma - \beta P_2 + \gamma(l_2 - l_1). \tag{2}$$

The probabilities that consumers purchase low-carbon products from online and offline channels are set to a and $(1-a)$, and the potential size of demand markets is set as σ. The price sensitivity coefficient of consumers is set as β, and the retail prices of online retailers and offline stores are set as P_1 and P_2. The transfer coefficient of consumers' demand to the difference in low-carbon advertising level is set as γ, and low-carbon advertising levels of online retailers and offline stores are set as l_1 and l_2.

This article uses the parameters shown in Table 2.

Among them, $j = d, r, a, c$ represent the fair and neutral decentralized decision-making (FNDD), the decentralized decision-making considering Nash bargaining fairness concerns (NBFDD), the decentralized decision-making considering absolute fairness concerns (AFDD), and the fair and neutral centralized decision-making (FNCD).

3.1. Decentralized Decision-Making Model with Fairness and Neutrality (Model I)

3.1. Decentralized Decision-Making Model with Fairness and Neutrality (Model I). Under FNDD, the supply chain members pursue the maximization of their interests. The

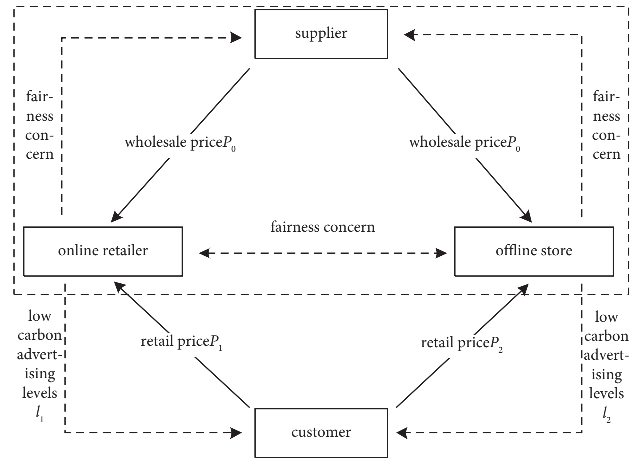

Figure 1: Decision relation of dual-channel supply chain considering fairness concerns.

revenue functions of online retailers, offline stores, suppliers, and the whole supply chain system are

$$\begin{aligned}\Pi_o^d &= (P_1 - P_0)\sigma_1 - \frac{1}{2}l_1^2 \\ &= (P_1 - P_0)(a\sigma - \beta P_1 + \gamma(l_1 - l_2)) - \frac{1}{2}l_1^2,\end{aligned} \tag{3}$$

$$\begin{aligned}\Pi_r^d &= (P_2 - P_0)\sigma_2 - \frac{1}{2}l_2^2 \\ &= (P_2 - P_0)((1-a)\sigma - \beta P_2 + \gamma(l_2 - l_1)) - \frac{1}{2}l_2^2,\end{aligned} \tag{4}$$

$$\begin{aligned}\Pi_m^d &= (P_0 - c)(\sigma_1 + \sigma_2) \\ &= (P_0 - c)(\sigma - \beta(P_1 + P_2)).\end{aligned} \tag{5}$$

3.2. Decentralized Decision-Making Model considering Nash Bargaining Fairness Concerns (Model II). This section further considers supply chain members' Nash bargaining fairness concerns based on Model I. In this model, the goal of supply chain members is not to maximize their interests but to pursue the fairness of their interests in the supply chain and formulate corresponding pricing strategy. The profits of Nash equilibrium bargaining relative reference points of online retailers, offline stores, and suppliers are $\overline{\Pi_o}$, $\overline{\Pi_r}$, and $\overline{\Pi_m}$. The utility functions of online retailers, offline stores, and suppliers are

$$U_o^f = \Pi_o + n_1(\Pi_o - \overline{\Pi_o}), \tag{6}$$

$$U_r^f = \Pi_r + n_2(\Pi_r - \overline{\Pi_r}), \tag{7}$$

$$U_m^f = \Pi_m + n_3(\Pi_m - \overline{\Pi_m}). \tag{8}$$

Equations (6)–(8) reflect the changes in the fair utility of the supply chain members' profit relative to the fairness reference points, reflecting the characteristics of profit

Table 2: Variables and descriptions.

Variables	Descriptions
σ	Potential size of demand markets
σ_1^j, σ_2^j	Sales volumes of online retailers and offline stores under four decisions
$a, 1-a\,(0<a<1)$	The probability that consumers purchase low-carbon products online and offline
$\beta\,(0<\beta<1)$	The price sensitivity coefficient of consumers
$\gamma\,(0<\gamma<1)$	The transfer coefficient of consumers' demand to the difference in low-carbon advertising level
c	Production cost
P_0	Wholesale price
P_1^j, P_2^j	Retail prices of online retailers and offline stores under four decisions
l_1^j, l_2^j	Low-carbon advertising level of online retailers and offline stores under four decisions
$\prod_i^j\,(i=o,r,m;\ j=d)$	Profits of online retailers, offline stores, and suppliers under FNDD
$U_i^j\,(i=o,r,m;\ j=r,a)$	Utilities of online retailers, offline stores, and suppliers under NBFDD and AFDD
Π^j	Overall profits of suppliers, online retailers, and offline stores under four decisions
$n_1, n_2, n_3\,(n_1, n_2, n_3 \geq 0)$	The Nash bargaining fairness concerns coefficient for online retailers, offline stores, and suppliers
$n, m\,(n, m \geq 0)$	The horizontal and vertical fairness concerns coefficient

beyond or below the fairness reference point of Nash bargaining [31].

Proposition 1. *We assume that the fairness concerns coefficients of online retailers and offline stores are equal, and there is $n_1 = n_2$, namely, $\overline{\Pi_o} = \overline{\Pi_r} = 1 + n_1/3 + 2n_1 + n_3\Pi$. The expected revenue functions of online retailers, offline stores, and suppliers are*

$$\begin{aligned}
U_o^f &= (1+n_1)\Pi_o + \frac{1+n_1}{3+2n_1+n_3}\Pi = (1+n_1)\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2\right] \\
&\quad + \frac{1+n_1}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right] \\
U_r^f &= (1+n_1)\Pi_r + \frac{1+n_1}{3+2n_1+n_3}\Pi = (1+n_1)\left[(P_2-P_0)(a\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2\right] \\
&\quad + \frac{1+n_1}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right] \\
U_m^f &= (1+n_3)\Pi_m + \frac{1+n_3}{3+2n_1+n_3}\Pi = (1+n_3)(P_0-c)(\sigma-\beta(P_1+P_2)) \\
&\quad + \frac{1+n_3}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right].
\end{aligned} \tag{9}$$

3.3. Decentralized Decision-Making Model considering Absolute Fairness Concerns (Model III). Based on Model I, this section further considers that all supply chain members have absolute fairness concerns. In this model, the goal of supply chain members is no longer to maximize benefits but to maximize utility compared with other members' benefits and formulate corresponding pricing strategy. Assuming that there are horizontal fairness concerns between online and offline channels of the supply chain, the horizontal fairness concerns coefficient is denoted as $n\,(n>0)$, there are vertical fairness concerns between suppliers and retailers, and the vertical fairness concerns coefficient is denoted as $m\,(m>0)$. The utility functions of online retailers, offline stores, and suppliers are

$$U_o^a = \Pi_o - n(\Pi_r - \Pi_o) - m(\Pi_m - \Pi_o) = (1+m+n)\Pi_o - n\Pi_r - m\Pi_m, \tag{10}$$

$$U_r^a = \Pi_r - n(\Pi_o - \Pi_r) - m(\Pi_m - \Pi_r) = (1+m+n)\Pi_r - n\Pi_o - m\Pi_m, \tag{11}$$

$$U_m^a = \Pi_m - m(\Pi_o - \Pi_m) - m(\Pi_r - \Pi_m) = (1+2m)\Pi_m - m\Pi_o - m\Pi_r. \tag{12}$$

Equations (10)–(12) reflect the changes in the fair utility of the supply chain members' profit compared with other members' income [28].

The expected utility functions of online retailers, offline stores, and suppliers under decentralized decision-making considering the absolute fairness concerns of supply chain members are

$$\begin{aligned} U_o^a &= (1+m+n)\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2))-\frac{1}{2}l_1^2\right] \\ &\quad -n\left[(P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1))-\frac{1}{2}l_2^2\right]-m[(P_0-c)(\sigma-\beta(P_1+P_2))] \\ U_r^a &= (1+m+n)\left[(P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1))-\frac{1}{2}l_2^2\right] \\ &\quad -n\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2))-\frac{1}{2}l_1^2\right]-m[(P_0-c)(\sigma-\beta(P_1+P_2))] \\ U_m^a &= (1+2m)[(P_0-c)(\sigma-\beta(P_1+P_2))]-m\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2))-\frac{1}{2}l_1^2\right] \\ &\quad -m\left[(P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1))-\frac{1}{2}l_2^2\right]. \end{aligned} \tag{13}$$

3.4. Centralized Decision-Making Model with Fairness and Neutrality (Model IV). Under FNCD, all members in the supply chain are regarded as a whole enterprise, and they cooperate to make decisions. The goal of enterprise operation is to maximize the profit of supply chain.

The overall revenue function of online retailers, offline stores, and suppliers is

$$\begin{aligned} \Pi^c &= (P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) \\ &\quad -\frac{1}{2}l_1^2+(P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) \\ &\quad -\frac{1}{2}l_2^2+(P_0-c)(\sigma-\beta(P_1+P_2)). \end{aligned} \tag{14}$$

Proposition 2. *Optimal pricing, sales volumes, and profits of supply chain members under four decisions are shown in Table 3.*

The optimal policies of FNDD, NBFDD, AFDD, and FNCD are solved through the converse solution method. The optimal retail prices and sales volumes of online retailers and offline stores are obtained as shown in Table 3 under four decisions. In addition, the profits of supply chain members are shown under four models.

4. Model Comparison Analysis

This section compares retail prices and sales volumes of online retailers and offline stores under four decisions and examines the impact of different reference points. At the same time, we analyze the influence of low-carbon advertising level difference on retail prices of online retailers and offline stores under four decisions. See Appendix for a specific solution process.

Proposition 3. The retail prices of online retailers and offline stores in AFDD are greater than those in FNDD, the retail prices of online retailers and offline stores in FNDD are greater than those in NBFDD, and the three are greater than those in FNCD.

The retail price of AFDD is further improved based on the dual marginal effects of FNDD among four decisions. In addition, supply chain members seek equitable interests and reduce retail prices to reduce the loss of interests caused by the dual marginal effects of decentralized decision-making in NBFDD. Supply chain members regard the whole supply chain system as a whole enterprise and pursue the maximization of enterprise interests so that the retail prices of online retailers and offline stores in NFCD are the lowest.

Proposition 4. *In FNCD, the sales volumes of online retailers and offline stores are higher than those in NBFDD, and the sales volumes in FNCD and NBFDD are higher than those in FNDD. The three are higher than those in AFDD.*

Among four decisions, the sales volumes of online retailers and offline stores in AFDD are the lowest. It will further the dual marginal effect compared with FNDD. In addition, it seeks the fairness of interests in NBFDD. Supply chain members improve their retail prices to reduce the loss of their interests caused by the dual marginal effects of decentralized decision-making. It will lead to the decrease of sales volumes. In FNCD, supply chain members regard the entire supply chain system as an enterprise, pursuing the maximization of enterprise interests. Therefore, the sales volumes of online and offline retailers in FNCD are the biggest.

Proposition 5. *In four decision models, the retail prices of online retailers are positively related to low-carbon*

Table 3: Optimal pricing, sales volumes, and profits of supply chain members under four decisions.

Fair and neutral decentralized decision-making (FNDD)	Decentralized decision-making considering Nash bargaining fairness concerns (NBFDD)	Decentralized decision-making considering absolute fairness concerns (AFDD)	Fair and neutral centralized decision-making (FNCD)
P_1, $a\sigma+\beta P_0+r(l_1-l_2)/2\beta$	$(4+2n_1+n_3)(a\sigma+r(l_1-l_2))/2\beta(4+2n_1+n_3), +(3+2n_1+n_3)\beta P_0+\beta c/2\beta(4+2n_1+n_3)$	$(1+m+n)(a\sigma+r(l_1-l_2))/2\beta(1+m+n), +(1+2m+n)\beta P_0-m\beta c/2\beta(1+m+n)$	$a\sigma+\beta c+r(l_1-l_2)/2\beta$
P_2, $(1-a)\sigma+\beta P_0+r(l_2-l_1)/2\beta$	$(4+2n_1+n_3)((1-a)\sigma+r(l_2-l_1))/2\beta(4+2n_1+n_3), +(3+2n_1+n_3)\beta P_0+\beta c/2\beta(4+2n_1+n_3)$	$(1+m+n)((1-a)\sigma+r(l_2-l_1))/2\beta(1+m+n),$ $+(1+2m+n)\beta P_0-m\beta c/2\beta(1+m+n)$	$(1-a)\sigma+\beta c+r(l_2-l_1)/2\beta$
σ_1, $a\sigma+r(l_1-l_2)-\beta P_0/2$	$(4+2n_1+n_3)(a\sigma+r(l_1-l_2))/2(4+2n_1+n_3), -(3+2n_1+n_3)\beta P_0-\beta c/2(4+2n_1+n_3)$	$(1+m+n)(a\sigma+r(l_1-l_2))/2(1+m+n), -(1+2m+n)\beta P_0+m\beta c/2(1+m+n)$	$a\sigma+r(l_1-l_2)-\beta c/2$
σ_2, $(1-a)\sigma+r(l_2-l_1)-\beta P_0/2$	$(4+2n_1+n_3)((1-a)\sigma+r(l_2-l_1))/2(4+2n_1+n_3), -(3+2n_1+n_3)\beta P_0-\beta c/2(4+2n_1+n_3)$	$(1+m+n)((1-a)\sigma+r(l_2-l_1))/2(1+m+n),$ $-(1+2m+n)\beta P_0+m\beta c/2(1+m+n)$	$(1-a)\sigma+r(l_2-l_1)-\beta c/2$
Π_o, $(a\sigma+r(l_1-l_2)-\beta P_0)^2/4\beta-\frac{1}{2}l_1^2$	$[(4+2n_1+n_3)(a\sigma+r(l_1-l_2))/2\beta(4+2n_1+n_3), -(5+2n_1+n_3)\beta P_0+\beta c/2\beta(4+2n_1+n_3),$ $[(4+2n_1+n_3)(a\sigma+r(l_1-l_2))/2(4+2n_1+n_3), -(3+2n_1+n_3)\beta P_0-\beta c]/2(4+2n_1+n_3)-\frac{1}{2}l_1^2$	$[(1+m+n)(a\sigma+r(l_1-l_2))/2\beta(1+m+n), -(1+n)\beta P_0-m\beta c]/2\beta(1+m+n),$ $[(1+m+n)(a\sigma+r(l_1-l_2))/2(1+m+n),$ $-(1+2m+n)\beta P_0+m\beta c]/2(1+m+n)-\frac{1}{2}l_1^2$	$(a\sigma+r(l_1-l_2)-\beta c)^2/4\beta-(1/2)l_1^2$
Π_r, $((1-a)\sigma+r(l_2-l_1)-\beta P_0)^2/4\beta-\frac{1}{2}l_2^2$	$(((4+2n_1+n_3)((1-a)\sigma+r(l_2-l_1)))/(2\beta(4+2n_1+n_3))),$ $((-(5+2n_1+n_3)\beta P_0+\beta c])/(2\beta(4+2n_1+n_3))),$ $[(4+2n_1+n_3)((1-a)\sigma+r(l_2-l_1))/2(4+2n_1+n_3), -(3+2n_1+n_3)\beta P_0-\beta c/2(4+2n_1+n_3)-\frac{1}{2}l_2^2$	$[(1+m+n)((1-a)\sigma+r(l_2-l_1))/2\beta(1+m+n),$ $-(1+n)\beta P_0-m\beta c]/2\beta(1+m+n), [(1+m+n)((1-a)\sigma+r(l_2-l_1))/2(1+m+n),$ $[-(1+2m+n)\beta P_0+m\beta c]/2(1+m+n)-\frac{1}{2}l_2^2$	$((1-a)\sigma+r(l_2-l_1)-\beta c)^2/4\beta-\frac{1}{2}l_2^2$
Π_m, $(P_0-c)(\sigma-2\beta P_0)/2$	$(P_0-c)((4+2n_1+n_3)\sigma/2(4+2n_1+n_3), -2(3+2n_1+n_3)\beta P_0-2\beta c)/2(4+2n_1+n_3)$	$(P_0-c)((1+m+n)\sigma/2(1+m+n), -2(1+2m+n)\beta P_0+2m\beta c)/2(1+m+n)$	$(P_0-c)(\sigma-2\beta c)/2$

Table 4: Parameter assignment.

Parameter	σ	a	P_0	c	r	β	l_1	l_2
Value	100	0.4	50	40	0.5	0.6	3	5

Table 5: Optimal decision values and profit values of four decisions.

	P_1	P_2	σ_1	σ_2	Π_o	Π_r	Π_m	Π
FNDD	57.5	74.2	4.5	15.5	29.3	362.1	200.0	591.4
NBFDD	56.7	73.4	5.0	16.0	28.9	360.9	209.4	599.2
AFDD	59.0	75.7	3.6	13.6	27.8	336.5	171.5	535.8
FNCD	52.5	69.2	7.5	18.5	14.3	342.1	260	616.4

advertising level difference of online retailers and offline stores. As the ratio of the transfer coefficient of consumers' demand to the difference in low-carbon advertising level and the price sensitivity coefficient of consumers increases, the retail prices of online retailers increase. The retail prices of offline stores are the opposite.

In four decision models, online retailers increase their retail prices to decrease their low-carbon advertising costs and obtain more profits with the increase of low-carbon advertising level difference of online retailers and offline stores. Meanwhile, the offline stores decrease their retail prices to obtain market competitiveness with the increase of low-carbon advertising level difference of online retailers and offline stores. When the transfer coefficient of consumers' demand to the difference in low-carbon advertising level is bigger than the price sensitivity coefficient of consumers, the low-carbon level mainly affects consumer decisions. When the low-carbon level of online retailers is higher than that of offline stores, consumers choose more online channels, and online retailers raise prices to reduce the loss of benefits. The retail prices of offline stores are the opposite.

Proposition 6. *The profit of the supply chain system under FNCD is more significant than that under FNDD.*

In FNCD, supply chain members work together to set the prices of products, pursue profit maximization, and create a win-win situation for the whole system. In order to maximize their profits, online retailers and offline stores increase their sales prices, leading to a decline in sales volumes in FNDD. Suppliers pursue profit maximization and increase wholesale prices, eventually leading to profits for online and offline stores and the entire supply chain system. Therefore, the profit of the supply chain system under the centralized decision-making is more significant compared with that under the decentralized decision-making.

5. Numerical Simulation

In the previous part, we used the Stackelberg game to study the pricing decisions of supply chain members under FNDD, NBFDD, AFDD, and FNCD models and analyzed the influence of low-carbon advertising level difference of online retailers and offline stores on the optimal decisions of different models. This section compares the optimal decisions and profit values under four decisions by numerical simulation. In order to better verify the above propositions, this section verifies and analyzes the above propositions through MATLAB software. The parameter distribution is shown in Table 4.

The optimal decisions and profit values under four decisions are shown in Table 5. The Nash bargaining fairness concerns coefficient of online retailers, offline stores, and suppliers in Model II is 0.8, and the horizontal and vertical fairness concerns coefficient in Model III is 0.8.

It can be seen from Table 5 that the retail prices of online retailers and offline stores under AFDD are higher than those under FNDD, and those under NBFDD are higher than those under FNCD. Proposition 3 is proven. Considering that the sales volumes of online retailers and offline stores in FNCD are higher than those in FNCD, both are higher than those in FNDD. The three are higher than the sales volumes in AFDD and Proposition 4 is proven.

In short, Nash bargaining fairness concerns behavior among supply chain members can reduce the marginal effect of the dual-channel supply chain. At the same time, online retailers and offline stores reduce retail prices to a certain extent and improve consumer satisfaction and loyalty. It will further strengthen the dual marginal utility of decentralized decision-making, improve retail prices, and reduce sales volumes in AFDD. Therefore, supply chain members should take their profits as the reference point and pay attention to the distribution fairness of their profits in supply chain system.

In addition, Table 5 shows that the profit of the supply chain system under FNCD and the sales volumes of online retailers and offline stores are the highest. This is because dual-channel supply chain members maximize the system's overall benefits as the goal under FNCD. Proposition 6 is further verified.

6. Conclusion and Managerial Insights

6.1. Conclusion. This paper discusses the influence mechanism of pricing decisions in the dual-channel supply chain under different fairness reference points and finds a possible behavior induction path. Meanwhile, this paper studies pricing strategies of dual-channel supply chain members considering different fairness reference points and consumer price sensitivity coefficient among supply chain members and analyzes the impact of changes in the fairness reference points of supply chain members on pricing strategies. Besides, this paper explores the relationship between the low-carbon advertising level difference and retail prices of online retailers and offline stores. This paper draws the following conclusions:

(1) Under four decisions, the retail prices of online retailers are positively related to low-carbon advertising level difference of online retailers and offline stores, and the retail prices of offline stores are the opposite.

(2) Supply chain members' attention to Nash bargaining fairness reduces the price of low-carbon products to a certain extent and improves the sales volumes. At the same time, the absolute fairness concerns behavior of supply chain members aggravates the marginal effect of the dual-channel supply chain. The sales volumes of online retailers and offline stores in NBFDD are higher than those in FNCD. They are all higher than the sales volumes under FNDD, and all three are higher than the sales volumes under AFDD. Retail prices are the opposite.

In this paper, we analyze the impact of different fairness preferences on supply chain pricing decisions when online and offline retailers' Nash bargaining fairness concerns coefficients are the same. The Nash bargaining fairness problem with entirely different fairness concerns of members could be considered in the dual-channel supply chain, and its impact on supply chain pricing decisions could be analyzed in the future.

6.2. Managerial Insights. In this section, some helpful management insights are generated through the numerical simulation analysis of this study.

6.2.1. Supply Chain Members' Approach to Fairness Concerns. Supply chain members should continuously deepen the concept of Nash bargaining fairness in corporate culture and create a fair system and cultural atmosphere. When choosing partners, suppliers and retail enterprises should choose enterprises with their profits as reference points, reduce retail prices, improve sales volumes, and reduce the marginal effect in the dual-channel supply chain to some extent.

6.2.2. Supply Chain Members' Approach to Improving Low-Carbon Advertising Level. Retail enterprises should increase investment in low-carbon advertising, improve quality green products for consumers, improve consumer satisfaction, improve consumer low-carbon sensitivity coefficient, and promote the sustainable development of the low-carbon industry. Online and offline retailers should organize carbon emission reduction activities to improve consumers' awareness of low-carbon environmental protection and promote the sustainable development of low-carbon products.

Appendix

A Proof of Proposition 1

Referencing the model construction of literature [31], we can obtain $\Pi_o + \Pi_r + \Pi_m = \Pi$ and $\overline{\Pi_o} + \overline{\Pi_r} + \overline{\Pi_m} = \Pi$.

According to the axiomatic definition of the Nash bargaining game solution, the Nash bargaining fairness reference points are the solution of the following Nash bargaining game model:

$$\begin{cases} \max\limits_{\Pi, U_o^f, U_r^f} U_o^f U_r^f U_m^f \\ s.t. \Pi_o + \Pi_r + \Pi_m = \Pi \\ \overline{\Pi_o} + \overline{\Pi_r} + \overline{\Pi_m} = \Pi \\ U_o^f \geq 0, U_r^f \geq 0, U_m^f \geq 0 \end{cases} \tag{A.1}$$

Equation (A.1) can be expressed as

$$\begin{cases} \max\limits_{\Pi, U_o^f, U_r^f} \left[(1+n_1)\Pi_o - n_1\overline{\Pi_o}\right]\left[(1+n_2)\Pi_r - n_2\overline{\Pi_r}\right]\left[(1+n_3)(\Pi - \Pi_o - \Pi_r) - n_3(\Pi - \overline{\Pi_o} - \overline{\Pi_r})\right], \\ U_o^f \geq 0, U_r^f \geq 0, U_m^f \geq 0. \end{cases} \tag{A.2}$$

For the second derivative Π_o, we can get $\partial^2 (U_o^f U_r^f U_m^f)/\partial\Pi_o^2 = -2(1+n_1)(1+n_3)[(1+n_2)\Pi_r - \overline{\Pi_r}] < 0$ and $\partial^2 (U_o^f U_r^f U_m^f)/\partial\Pi_r^2 = -2(1+n_2)(1+n_3)[(1+n_1)\Pi_o - \overline{\Pi_o}] < 0$. It is shown that Nash equilibrium bargaining has a unique optimal solution. Making $\partial(U_o^f U_r^f U_m^f)/\partial\Pi_o = 0$ and $\partial(U_o^f U_r^f U_m^f)/\partial\Pi_r = 0$, the optimal solutions of Nash equilibrium bargaining are $\Pi_o = \overline{\Pi_o}$ and $\Pi_r = \overline{\Pi_r}$. Bringing in $\partial(U_o^f U_r^f U_m^f)/\partial\Pi_o = 0$ and $\partial(U_o^f U_r^f U_m^f)/\partial\Pi_r = 0$, we can get $\overline{\Pi_o}$ and $\overline{\Pi_r}$. From $\overline{\Pi_m} = \Pi - \overline{\Pi_o} - \overline{\Pi_r}$, we can get $\overline{\Pi_m}$. That is, $\overline{\Pi_o} = 1 + n_1/3 + n_1 + n_2 + n_3\Pi$, $\overline{\Pi_r} = 1 + n_2/3 + n_1 + n_2 + n_3\Pi$, and $\overline{\Pi_m} = 1 + n_3/3 + n_1 + n_2 + n_3\Pi$.

The expected revenue functions of online retailers, offline stores, and suppliers are

$$\begin{aligned}
U_o^f & \\
&+ \frac{1+n_1}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right],\\
U_r^f &= (1+n_1)\Pi_r + \frac{1+n_1}{3+2n_1+n_3}\Pi = (1+n_1)\left[(P_2-P_0)(a\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2\right]\\
&+ \frac{1+n_1}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right],\\
U_m^f &= (1+n_3)\Pi_m + \frac{1+n_3}{3+2n_1+n_3}\Pi = (1+n_3)(P_0-c)(\sigma-\beta(P_1+P_2))\\
&+ \frac{1+n_3}{3+2n_1+n_3}\left[(P_1-P_0)(a\sigma-\beta P_1+\gamma(l_1-l_2)) - \frac{1}{2}l_1^2 + (P_2-P_0)((1-a)\sigma-\beta P_2+\gamma(l_2-l_1)) - \frac{1}{2}l_2^2 + (P_0-c)(\sigma-\beta(P_1+P_2))\right].
\end{aligned} \tag{A.3}$$

B Proof of Proposition 2

For the retail prices, sales volumes, and profits of online retailers and offline stores under FNDD, through the reverse induction method, the second-order partial derivatives of Π_o^d on P_1 are first obtained and $\partial^2\Pi_o^d/\partial P_1^2 < 0$ is known, so there is a unique optimal solution on P_1. Making $\partial\Pi_o^d/\partial P_1 = 0$, we can obtain retail prices of the online retailers as

$$P_1^d = \frac{a\sigma + \beta P_0 + \gamma(l_1 - l_2)}{2\beta}. \tag{B.1}$$

The second-order partial derivatives of Π_r^d on P_2 are first obtained and $\partial^2\Pi_r^d/\partial P_2^2 < 0$ is known, so there is a unique optimal solution on P_2. Making $\partial\Pi_r^d/\partial P_2 = 0$, we can get retail prices for offline stores as

$$P_2^d = \frac{(1-a)\sigma + \beta P_0 + \gamma(l_2 - l_1)}{2\beta}. \tag{B.2}$$

Substituting P_1^d and P_2^d in equations (1) and (2), we can get online retailers and offline store sales volumes as

$$\sigma_1^d = \frac{a\sigma + \gamma(l_1 - l_2) - \beta P_0}{2}, \sigma_2^d = \frac{(1-a)\sigma + \gamma(l_2 - l_1) - \beta P_0}{2}. \tag{B.3}$$

Substituting P_1^d, P_2^d, σ_1^d, and σ_2^d in equations (3)–(5), we can get the sales volumes of online retailers and offline stores as

$$\begin{aligned}
\Pi_o^d & \\
&= \frac{((1-a)\sigma + \gamma(l_2-l_1) - \beta P_0)^2}{4\beta} - \frac{1}{2}l_2^2\Pi_m^d \\
&= \frac{(P_0-c)(\sigma - 2\beta P_0)}{2}.
\end{aligned} \tag{B.4}$$

The proofs of Model II, Model III, Model IV, and Model I are similar, so they are omitted.

C Proof of Proposition 3

$$\begin{aligned}
P_1^a - P_1^d & \\
&= \frac{(P_0-c)(3+2n_1+n_3)}{2(4+2n_1+n_3)}.
\end{aligned} \tag{C.1}$$

It is easy to know that $P_1^a > P_1^d$, $P_1^d > P_1^f$, and $P_1^f > P_1^c$, so $P_1^a > P_1^d > P_1^f > P_1^c$.

The proofs of offline stores' retail prices are similar to those of online retailers, so they are omitted.

D Proof of Proposition 4

$$\sigma_1^c - \sigma_1^f = \frac{m\beta(P_0 - c)}{2(1+m+n)}. \tag{D.1}$$

It is easy to know that $\sigma_1^c > \sigma_1^f$, $\sigma_1^f > \sigma_1^d$, and $\sigma_1^d > \sigma_1^a$, so $\sigma_1^c > \sigma_1^f > \sigma_1^d > \sigma_1^a$.

The proofs of offline stores' sales volumes are similar to those of online retailers, so they are omitted.

E Proof of Proposition 5

It is easy to know that $\partial P_1^d/\partial(l_1 - l_2) = r/2\beta > 0$ and $\partial P_2^d/\partial(l_1 - l_2) = -r/2\beta < 0$.

The proofs of Model II, Model III, and Model IV are similar to that of Model I, so they are omitted.

F Proof of Proposition 6

It is easy to know that $P_0 > c$ and $\sigma > 2\beta c$, so there is

$$\Pi^c - \Pi^d - \left(\frac{(a\sigma + \gamma(l_1 - l_2) - \beta P_0)^2}{4\beta} - \frac{1}{2}l_1^2 + \frac{((1-a)\sigma + \gamma(l_2 - l_1) - \beta P_0)^2}{4\beta} - \frac{1}{2}l_2^2 + \frac{(P_0 - c)(\sigma - 2\beta P_0)}{2}\right) = \frac{(\sigma - 2\beta c)(P_0 - c)}{2} > 0. \tag{F.1}$$

Data Availability

The data used to support the results of this study are available from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Hong Huo and Dan Luo conceived and designed the study, contributed significantly to the analysis and manuscript preparation, performed the model analyses, and wrote the manuscript. Zhanghua Yan and Hao He performed the analysis by reviewing and editing. All authors have agreed on the published version of the manuscript.

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Research Article

A Novel Approach for Sustainable Supply Chain Management with Analyzing the Effective Governance under Fuzzy Uncertainty

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Nowadays, knowledge has become one of the most important tools of power, distributing public services that accept the audience as citizens and not consumers and provide the principle of services without financial worries. Moreover, the urban products have a specific production and distribution channel that should be assessed. In this research, a mathematical framework is proposed for designing the supply chain network of urban products. The main contribution of this research is to incorporate the effect of public service into urban products' supply chain planning. In this regard, a mixed-integer mathematical model is proposed. In this mathematical model, an attempt is made to minimize the costs of the product distribution system by considering the effects of production, maintenance, and distribution. Moreover, fuzzy uncertainty has been applied to adapt the mathematical model to real conditions. The numerical results show that if manufacturers and distributors want to strengthen their institutions and maintain their leadership roles as in the past, they can optimize their distribution network structure to achieve the best possible performance. Moreover, technological advances and innovations in production and distribution systems can create a huge leap in profitability.

1. Introduction

Since the existence of human beings, there has been change and transformation all over the world, in every field. In particular, states have turned into traditional, modern, post-modern, liberal, interventionist, regulatory, and reregulating state understanding. In the transformation process of the state, the organizational structure, the service, and management it carries out have changed along with it, and the public administration, which is the state's functioning mechanism and means of providing public services, has been at the center of this differentiation. In this regard, urban and rural transportation for required products is one of the most important factors for providing suitable sustainable development [1, 2].

In addition to production and distribution, new methods have revealed ways to provide faster, more effective, and quality public services to citizens, business circles, and nongovernmental organizations [3].

The study consists of five sections. First, the transition from management understanding the rural transportation of required products as a result of changes in public administration is discussed, and the related concepts are explained. Then, a novel mathematical model is proposed to find optimal decisions. Next, the numerical results are presented, and finally, the discussion is provided.

2. Literature Review

Public administration, which has become an integral part of daily life as the state's means of action and business, has constantly been changing with the growth and development of the state and the increasing needs of the people from the early ages to the present day [4, 5].

In the nineteenth century, the state was traditionally the Gendarmerie, which had classical duties such as security, justice, and foreign policy, and it rapidly changed as a result of economic issues (1929 and 1973 crises) at the beginning of the twentieth century [6]. The change of the state has also changed the understanding of public administration [7].

As a result, researchers suggested that the state should take guiding decisions in order to ensure efficient use of resources in the economy, have a fair distribution of income, achieve economic growth and development, and ensure economic stability, that is, the state should be steering rather than rowing [8]. With Keynes's policies, it was accepted that the state should take a more active role in the economic and social field [8, 9].

There was a need for an understanding to make public administration both efficient and responsible for its decisions and transactions [10]. The spread of democratization discourses after 1980, localization, globalization, technological development, and the importance of nongovernmental organizations transformed the understanding of public administration into a new understanding of public administration [11]. The new public management approach is a flexible, transparent structure that defends the application of market techniques to the public, gives the manager wide authority, brings competition to the public sector, citizen-centered, soft hierarchy, and decentralization [12]. The new public administration aims to eliminate bureaucracy and paperwork in public, accelerate access to services with the effective and efficient use of technology, and use public resources more efficiently with target-oriented, performance-based service delivery [13].

These are considered key factors in determining the level of good governance [14]. There is also a relationship between democracy and good governance, as good governance is located in a functioning democratic system with freedom of expression, equality, and a sound legal system [15]. Similarly, the United Nations Economic and Social Commission for Asia and Pacific has listed eight main features of good governance: participatory, consensus and legal rules, accountable, transparent, sensitive, effective and efficient, and equitable. Good governance aims to provide more and higher-quality services to the public at less cost [16, 17]. It does this only with an accountable, participatory, transparent, and effective management approach [18].

Therefore, there is no general definition of public service. Public service, which is one of the most fundamental issues of administrative law, is the activity carried out by public legal entities or private persons under their control in order to satisfy a common and general need that has gained importance in society [19].

Public service is the activities carried out by the state and other public institutions directly or under the strict supervision, control, and responsibility of a public institution to meet the needs of society. Public service is an activity for the purpose of the public benefit provided or undertaken by a public legal entity [20].

Public service can improve public product distributions [21]. In organic terms, the public service is defined as the whole of agents and means allocated by a public legal entity to carry out certain tasks, while the public service in material terms is completely independent of the characteristics of the organization carrying out the activity, only by looking at the nature of the activity [22, 23]. In terms of form, public service refers to a particular procedure and a certain legal regime [21].

The principle of public service has a significant effect on public product distribution. Public product distribution meets public needs rather than private needs and targets the public good. The legislature will appreciate whether a need has gained social significance to the extent that it requires the establishment of public service [22–24].

The fact that commercial channels include more colorful entertainment programs has accelerated the attractiveness of the broadcasts to the audience. Therefore, most public service broadcasters have made some important changes to the program's appearance in the face of competition [25]. The globalizing communication environment has enabled public service broadcasting to become global, thus changing the traditional program strategy.

Public broadcasters have learned to adapt to commercial media markets by making their bureaucracies ruder and lean, choosing a middle ground between popularization and purification in their program strategy [26]. Based on this dominant approach, in terms of public service broadcasting, a management style in which the public is defined as a customer, competition is praised, and marketization and the understanding of earning income from external sources are encouraged has come to the fore [27].

After reviewing the different aspects of public service and urban products supply chain, the main research gap and the contribution of this research can be presented at the integration of public service quality and urban products supply chain planning using an optimization approach.

3. Materials and Methods

3.1. Public Broadcasting with Secondary Data. With the effect of technological developments in the twenty-first century, conditions have changed, and they continue to change day by day. Businesses are working to be able to survive in the global competition and maintain their existence. One of the most important means of achieving this is the strategic public relations function of the organizations and the corporate reputation management, which is one of the most important functions of this function [28]. In recent years, social media has started to be used in all areas. Institutions are also directed to social media and work to improve their corporate reputation in these environments. At this point, whether or not the fact that social media is used effectively by institutions is of utmost importance in terms of reputation [29, 30].

3.2. Proposed Mathematical Model. In this study, in order to show innovative activities in the automotive industry, a

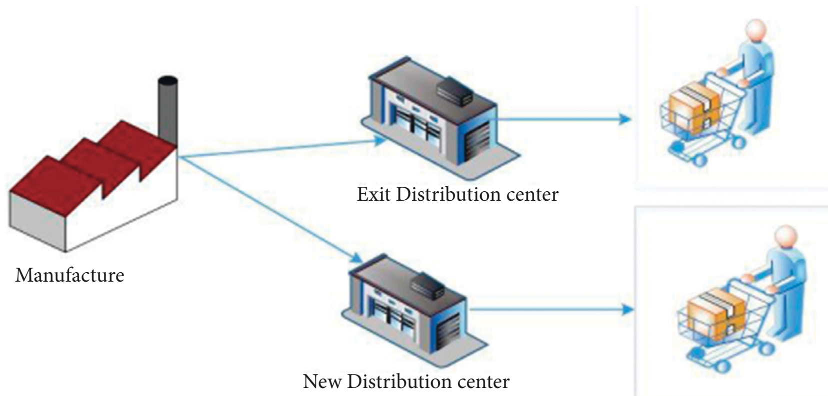

Figure 1: The studded transportation network.

mathematical model of inventory location to redesign warehouses in a multiproduct three-level supply chain for the automotive industry is presented. The structure of the proposed supply chain is inspired by [31–33]. The supply chain network in question includes the manufacturer, candidate points for the construction of new and existing warehouses, as well as customers, as shown in Figure 1.

Existing warehouses can be closed during one of the strategic planning periods, and during the planning period, new warehouses can be opened at one of the candidate points at different strength levels. If one of the active distribution centers is closed during the planning period, it cannot be activated until the end of the planned period, and if a new warehouse is built in one of the candidate points during one of the periods, it cannot be closed until the end of the period.

Active warehouses can increase their capacity over time. The costs considered in this section include the fixed cost of constructing a new warehouse, the cost of closing an existing plant, and the costs associated with increasing the capacity of active plants in each time period. Each customer is assigned to one of the active warehouses in each of the time periods, considering the capacity limit, and in each warehouse, based on the amount of demand allocated to the warehouse, they issue an order from the manufacturer [34].

A fixed amount inventory policy (Q, r) is considered taking into account the lack of recovery in each warehouse in order to determine the optimal order amount from the manufacturer. It should be noted that according to [34], the total cost of inventory in (Q, r) systems is calculated based on a nonlinear formulation.

In each of the time periods, a certain percentage of customer demand is faced with a shortage of backlog and is not met, and a percentage of the shortage is met in the next period. The costs considered in this section include inventory maintenance costs, warehouse ordering costs, the costs of transporting products from the manufacturer to the warehouses, the fixed cost of constructing the warehouses, the cost of closing the existing warehouses, the operating costs of the active warehouses in each period, as well as the costs of shortages. Due to the inherent uncertainty in the parameters of the problem, the parameters related to cost and customer demand have been considered fuzzy, and the efficient method of Jimmenez [35] has been used to deal with uncertainties [34].

3.2.1. Sets

$w \in w^e \cup w^n = \{1, 2, \ldots, w\}$: Set of warehouses

$w^e = \{1, 2, \ldots, w^e\}$: Set of available warehouses

$w^n = \{1, 2, \ldots, w^n\}$: Set of warehouses which are possible to establish

$k_w = \{1, 2, \ldots, k_w\}$: Set of warehouses capacity levels

$C = \{1, 2, \ldots, c\}$: Set of customers

$P = \{1, 2, \ldots, p\}$: Set of final products

$T = \{1, 2, \ldots, t\}$: Set of time periods

$T_L \in T = \{1, 2, \ldots, t_1\}$: Strategic time periods in which new facilities can be built, shut down existing facilities, and increase facility capacity

$U = \{1, 2, \ldots, u\}$: Set of consolidation levels

3.2.2. Parameters

fc_{tj}^u: Fixed cost of establishing a warehouse $j \in w^n$ at level of $u \in U$ in period $t \in T_1$

sc_{tj}: Fixed cost of closing warehouse $j \in w^e$ in period $t \in T_1$

ic_{tjk}: Cost of establishing capacity level $k \in k_w$ in location $j \in w$ in period $t \in T_1$

oc_{tj}: Operation cost in location $j \in w$ in period $t \in T$

sf_{tj}: Cost saving in closing warehouse $j \in w$ in period $t \in T_1$

fo_{wtp}: Fixed cost of transportation of product $p \in P$ from warehouse $w \in w^e \cup w^n$ in period $t \in T$

g_{wtp}: Fixed cost of ordering product $p \in P$ from warehouse $\in w^e \cup w^n$ in period $t \in T$

h_{wp}^t: Holding cost of product $p \in P$ in warehouse $w \in w^e \cup w^n$ in period $t \in T$

a_{twp}: Variable cost of distribution product $p \in P$ from warehouse $w \in w^e \cup w^n$ in period $t \in T$

Q^e_j: capacity of available warehouse $j \in w^e$ in period $t \in T$

l^p_{wt}: Lead time of product $p \in P$ in warehouse $w \in w^e \cup w^n$ in period $t \in T$

$\sigma^{2,t}_{cp}$: Variance of demand for customer $c \in C$ for product $p \in P$ in period $t \in T$

μ_{cpt}: Mean demand of customer $c \in C$ for product $p \in P$ in period $t \in T$

β: Weight of holding costs

θ: Weight of distribution costs

ρ_{tp}: Percentage of backorder of product $p \in P$ in period $t \in T$

π_0: Fixed cost of backorders

π_{tp}: Variable cost of backorder of product $p \in$ in period $t \in T$

ω_0: Fixed cost of lost sales

ω_{tp}: Variable cost of lost sales of product $p \in P$ in period $t \in T$

ξ_0: Average shortage cost

ξ_{tp}: Average shortage time in period $t \in T$

3.2.3. Variables

$Y^{nu}_{t,j}$: Binary variable and equal to 1 if warehouse $j \in w^n$ is established in period $t \in T_L$ in consolidation level $u \in U$

$Y^e_{t,j}$: Binary variable and equal to 1 if warehouse in location $i \in w^e$ is closed in period $t \in T_L$

Z_{wcrtp}: Binary variable and equal to 1 if customer $c \in C$ is assigned to warehouse $w \in w^e \cup w^n$ in period $t \in T$ for providing product $p \in P$

U_{tjk}: Binary variable and equal to 1 if capacity level $k \in k_w$ is assigned to warehouse $j \in w$ in period $t \in T_L$

A^n_{tj}: Amount of capacity in warehouse $j \in w^e$ in period $t \in T$

A^e_{tj}: Amount of capacity in warehouse $j \in w^n$ in period $t \in T$

3.2.4. Mathematical Formulation

$$
\begin{aligned}
MinZ = {} & \sum_{t\in T_L}\sum_{j\in w^n}\sum_{u} fc^u_{tj} y^{nu}_{tj} + \sum_{t\in T_L}\sum_{j\in w^e} sc_{tj} Y^e_{tj} + \sum_{t\in T_L}\sum_{j\in w}\sum_{k\in k_j} ic_{tjk} U_{tjk} - \sum_{j\in w^e} sf_{tj}\left(\sum_{t\in T_L} Y^e_{tj}\right) \\
& + \left(\sum_{w}\sum_{p}\sum_{t}\sum_{c}\left(\sqrt{2\left(\theta f o_{\mathrm{wtp}} + \beta g_{\mathrm{wtp}}\right)\mu_{\mathrm{ctps}} Z_{\mathrm{wctps}} \theta h_{\mathrm{wtp}} - \frac{\theta h_{\mathrm{wtp}}\left(\xi_0 \mu_{\mathrm{ctp}} Z_{\mathrm{wctp}}\right)^2}{\theta h_{\mathrm{wtp}} + \xi_{tp}}}\sqrt{\frac{\xi_{tp}}{\theta h_{\mathrm{wtp}} + \xi_{tp}}}\right)\right. \\
& \left. + \theta \sum_{w}\sum_{p}\sum_{t}\sum_{c}\left(\frac{\theta h_{\mathrm{wtp}} \xi_0 \mu_{\mathrm{ctp}} Z_{\mathrm{wctp}}}{h_{\mathrm{wtp}} + \xi_{tp}}\right)\right) \\
= {} & \left(\theta \sum_{w}\sum_{p}\sum_{t}\sum_{c} Z_{\mathrm{wctp}} \mu_{\mathrm{ctp}} a_{\mathrm{wtp}} + \beta \sum_{w}\sum_{p}\sum_{t} h_{\mathrm{wtp}} Z_a \sqrt{L^p_{wt}\left(\sum_{c} \delta^t_{cp} Z_{\mathrm{wctp}}\right)} \sum_{w}\sum_{p}\sum_{t}\sum_{c} Z_{\mathrm{wctp}} \mu_{\mathrm{ctp}} a_{\mathrm{wtp}}\right. \\
& \left. + \sum_{r}\sum_{h}\sum_{t}\sum_{w} r h_{\mathrm{twr}} c r_{tw}\right),
\end{aligned} \tag{1}
$$

$$\sum_{t\in T_L}\sum_{u} Y^{un}_{tj} \le 1 \quad \forall j \in w^n, \tag{2}$$

$$\sum_{u} Y^{un}_{tj} \le \sum_{k\in k_j} U_{tkj} \le \sum_{\tau=1,\tau\in T_L}^{t}\sum_{u} Y^{un}_{\tau j} \quad \forall t \in T, j \in w^n, \tag{3}$$

$$\sum_{k\in k_j} U_{tkj} \le 1 - \sum_{\tau=1,\tau\in T_L}^{|T|} Y^e_{\tau j} \quad \forall t \in T_L, j \in w^e, \tag{4}$$

$$A^n_{tj} = A^n_{(t-1)j} + \sum_{k\in k_j} Q_{jk} u_{tjk} \quad \forall j \in w^n, t \in T, \tag{5}$$

$$A^e_{tj} = \sum_{k \in k_j} Q_{jk} u_{tjk} + A^e_{(t-1)j} \quad \forall j \in w^e, t \in T, \tag{6}$$

$$\sum_{j \in w} Z_{\text{jcpt}} = 1 \quad \forall j \in x^n, p \in P, c \in C, t \in T, \tag{7}$$

$$Z_{\text{jcpt}} \leq \sum_{\tau=1, \tau \in T_L}^{t} \sum_h Y^n_{\tau jh} \quad \forall j \in w^n, p \in P, t \in T, \tag{8}$$

$$Z_{\text{jcpt}} \leq 1 - \sum_{\tau=1, \tau \in T_L}^{|T|} \sum_h Y^e_{\tau j} \quad \forall j \in w^e, p \in P, t \in T, \tag{9}$$

$$\sum_c \sum_p Z_{jcpt} \mu_{ctp} \leq A^n_{tj} \quad \forall j \in w^e, p \in P, t \in T, \tag{10}$$

$$\sum_c \sum_p Z_{jcpt} \mu_{ctp} \leq A^e_{tj} \quad \forall j \in w^e, p \in P, t \in T, \tag{11}$$

$$Y^{n,u}_{t,j}, Y^e_{t,j}, Z_{jcpt}, U_{tjk} \in (0,1) \quad \forall j \in w, p \in P, t \in T, u \in U, \tag{12}$$

$$A^e_{tj}, A^n_{tj} \geq 0 \quad \forall j \in w, p \in P, t \in T. \tag{13}$$

Equation (1) represents the objective function of the model. The objective function includes minimizing fixed ordering costs, transportation, variable ordering costs, inventory maintenance costs, shortage costs, fixed cost of new facility construction, fixed cost of closing the existing facility, cost of increasing facility capacity, and operating cost of the active facility. Equation (2) states that if it is activated in one of the facilitation periods, it should not be closed until the end of the period. Equation (3) is related to increasing the capacity of new facilities in each period and building capacity in the new facilities that are being built. Due to this limitation, the capacity of the facility can be increased if the facility is active during that period. Also, if a facility is activated in any period, one of the capacity levels must be allocated. Equation (4) states that the capacity of existing facilities can be increased if the existing facility remains active until the end of the period. Equations (5) and (6) carry out capacity planning for existing and constructed facilities in each period. The facilitation capacity in each time period is equal to the amount of capacity added in the desired period and the amount of capacity transferred from the previous period. Equation (7) states that each point of demand in each period for each product must be assigned to exactly one of the active facilities. Equations (8) and (9) state that a customer can be assigned to a facility over a period of time if the facility is active during that period. Equations (10) and (11) are related to the facility capacity constraints in each period. Equations (12) and (13) show the type of each decision variable.

3.2.5. Solution Method. In this research, in order to deal with the uncertainties in the cost parameters and the amount of customer demand, the Jimenez possibility method [35] has been used due to its high efficiency. The fuzzy method of Jimenez et al. is programmed based on the expected value and the expected game. Due to the efficiency and computational simplicity, the triangular fuzzy distribution method has been used to deal with the uncertain parameters of the model. Assuming ξ is a triangular fuzzy number, the membership function of this fuzzy number μ(x) is defined as follows:

$$\mu_\xi(x) = \begin{cases} f_\zeta(x) = \dfrac{x - \zeta^p}{\zeta^m - \zeta^p} & if\ \zeta^p \leq x \leq \zeta^m \\ 1 & if\ x = \zeta^m \\ g_\zeta(x) = \dfrac{\zeta^0 - x}{\zeta^0 - \zeta^m} & if\ \zeta^m \leq x \leq \zeta^0 \\ 0 & if\ x \leq \zeta^p\ or\ x \geq \zeta^0 \end{cases} \tag{14}$$

Expected income (EI) and trigonometric fuzzy numbers are obtained from equations (15) and (16):

$$\begin{aligned} EI(\xi) = \left[E_1^\zeta E_2^\zeta\right] &= \left[\int_0^1 f_\zeta^{-1}(x)dx \int_0^1 g_\zeta^{-1}(x)dx\right] \\ &= \left[\frac{1}{2}\left(\zeta^p + \zeta^m\right)\frac{1}{2}\left(\zeta^0 + \zeta^m\right)\right], \end{aligned} \tag{15}$$

$$EV(\xi) = \frac{E_1^\zeta + E_2^\zeta}{2} = \frac{\zeta^p + 2\zeta^m + \zeta^0}{4}. \tag{16}$$

Also, for the fuzzy number pairs $\tilde{a}$ and $\tilde{b}$, the degree to which $\tilde{a}$ is greater than $\tilde{b}$ is given in Equation (17):

$$\mu_M(x) = (a\%, b\%) = \begin{cases} 1 & if\, E_1^a > E_2^b \\ \dfrac{E_2^a - E_1^b}{E_2^a - E_1^b - \left(E_2^b - E_1^a\right)} & if\, E_1^a \in \left[E_1^a - E_2^b E_2^a - E_1^b\right] \\ 0 & if\, E_2^a > E_1^b \end{cases} \tag{17}$$

$\mu_M(a\%, b\%) \geq \alpha$ means that at degree α, a greater % is equal to b% and is defined as a% $\geq\_\alpha$ b%. In addition, for a pair of fuzzy numbers $\tilde{a}$ and $\tilde{b}$ which is equal to $\tilde{b}$, can say: $\tilde{a} \geq \tilde{b}, \tilde{a} \leq \tilde{b}$. Now consider the following fuzzy mathematical programming model in which all parameters are considered as fuzzy numbers.

$$\begin{aligned} &\min z = cx \\ &a_i x \geq b_i x\, i = 1, \ldots, l \\ &a_i x = b_i x\, i = l+1, \ldots, m \\ &x \geq 0. \end{aligned} \tag{18}$$

According to the Jimenez method [35], Equations (19) and (20) can be presented as the counterpart formulation of uncertain constraints.

$$\frac{E_2^{a_i x} - E_2^{b_i}}{E_2^{a_i x} - E_1^{b_i} - \left(E_1^{a_i x} - E_2^{b_i}\right)} \geq \alpha, \quad i = 1, \ldots, l \tag{19}$$

$$\frac{\alpha}{2} \leq \frac{E_2^{a_i x} - E_2^{b_i}}{E_2^{a_i x} - E_1^{b_i} - \left(E_1^{a_i x} - E_2^{b_i}\right)} \leq 1 - \frac{\alpha}{2}. \quad i = l+1, \ldots, m \tag{20}$$

Now according to Equations (18)–(20), the following formulation can be presented.

$$\left[(1-\alpha)E_2^{a_i} + \alpha E_1^{a_i}\right]x \geq (1-\alpha)E_1^{b_i} + \alpha E_2^{b_i}, \quad i = 1, \ldots, l \tag{21}$$

$$\left[\left(1 - \frac{\alpha}{2}\right)E_1^{a_i} + \frac{\alpha}{2}E_2^{a_i}\right]x \leq \left(1 - \frac{\alpha}{2}\right)E_2^{b_i} + \frac{\alpha}{2}E_1^{b_i}, \quad i = l+1, \ldots, m \tag{22}$$

$$\left[\left(1 - \frac{\alpha}{2}\right)E_2^{a_i} + \frac{\alpha}{2}E_1^{a_i}\right]x \geq \left(1 - \frac{\alpha}{2}\right)E_1^{b_i} + \frac{\alpha}{2}E_2^{b_i}, \quad i = l+1, \ldots, m \tag{23}$$

$$\begin{aligned} &\min EV(c\%)x \\ &\left[(1-\alpha)E_2^{a_i} + \alpha E_1^{a_i}\right]x \geq (1-\alpha)E_1^{b_i} + \alpha E_2^{b_i}\; i = 1, \ldots, l \\ &\left[\left(1 - \frac{\alpha}{2}\right)E_1^{a_i} + \frac{\alpha}{2}E_2^{a_i}\right]x \leq \left(1 - \frac{\alpha}{2}\right)E_2^{b_i} + \frac{\alpha}{2}E_1^{b_i} \\ &i = l+1, \ldots, m \\ &\left[\left(1 - \frac{\alpha}{2}\right)E_2^{a_i} + \frac{\alpha}{2}E_1^{a_i}\right]x \geq \left(1 - \frac{\alpha}{2}\right)E_1^{b_i} + \frac{\alpha}{2}E_2^{b_i} \\ &i = l+1, \ldots, m \end{aligned} \tag{24}$$

According to the Jimenez [35] method, the possibilistic model of multiproduct presented to redesign the supply chain network can be converted as follows:

$$
\begin{aligned}
MinZ = {} & \sum_{t\in T_L}\sum_{j\in w^n}\sum_{u}\left(\frac{FC_{tj}^{up}+2FC_{tj}^{um}+FC_{tj}^{uo}}{4}\right)y_{tj}^{nu}+\sum_{t\in T_L}\sum_{j\in w^e}\left(\frac{SC_{tj}^{p}+2SC_{tj}^{m}+SC_{tj}^{o}}{4}\right)Y_{tj}^{e}\\
& -\sum_{j\in w^e}\left(\frac{SC_{tj}^{p}+2SC_{tj}^{m}+SC_{tj}^{o}}{4}\right)\sum_{t\in T_L}Y_{tj}^{e})+\sum_{t\in T_L}\sum_{j\in w}\sum_{k\in k_j}\left(\frac{IC_{tjk}^{p}+2IC_{tjk}^{m}+IC_{tjk}^{o}}{4}\right)U_{tjk}\\
& +\left(\sum_{w}\sum_{p}\sum_{t}\sum_{c}\left(\sqrt{2\left(\theta fo_{wtp}+\beta g_{wtp}\right)\left(\frac{\mu_{ctps}^{o}+2\mu_{ctp}^{m}+\mu_{ctp}^{p}}{4}\right)Z_{wctps}\theta h_{wtp}-\frac{\theta h_{wtp}\left(\xi_0\left(\mu_{ctps}^{o}+2\mu_{ctp}^{m}+\mu_{ctp}^{p}/4\right)Z_{wctp}\right)^2}{\theta h_{wtp}+\xi_{tp}}}\right.\right.\\
& \left.\left.\cdot\sqrt{\frac{\xi_{tp}}{\theta h_{wtp}+\xi_{tp}}}\right)+\theta\sum_{w}\sum_{p}\sum_{t}\sum_{c}\left(\frac{\theta h_{wtp}\xi_0\left(\mu_{ctps}^{o}+2\mu_{ctp}^{m}+\mu_{ctp}^{p}/4\right)Z_{wctp}}{h_{wtp}+\xi_{tp}}\right)\right)\\
& +\left(\theta\sum_{w}\sum_{p}\sum_{t}\sum_{c}Z_{wctp}\left(\frac{\mu_{ctps}^{o}+2\mu_{ctp}^{m}+\mu_{ctp}^{p}}{4}\right)a_{wtp}\right.\\
& \left.+\beta\sum_{w}\sum_{p}\sum_{t}\left(h_{wtp}Z_a\sqrt{L_{wt}^{p}\left(\sum_{c}\delta_{cp}^{t}Z_{wctp}\right)\sum_{w}\sum_{p}\sum_{t}\sum_{c}Z_{wctp}\left(\frac{\mu_{ctps}^{o}+2\mu_{ctp}^{m}+\mu_{ctp}^{p}}{4}\right)a_{wtp}}\right)\right),
\end{aligned}
\tag{25}
$$

$$
\sum_{c}\sum_{p}Z_{jcpt}\left(\left(1-\frac{\alpha}{2}\right)\left(\frac{\mu_{ctp}^{p}+\mu_{ctp}^{m}}{2}\right)+\left(\frac{\alpha}{2}\right)\left(\frac{\mu_{ctp}^{o}+\mu_{ctp}^{m}}{2}\right)\right)\leq A_{tj}^{n}, \tag{26}
$$

$$j\in w^{n}, p\in P, t\in T$$

$$
\sum_{c}\sum_{p}Z_{jcpt}\left(\left(1-\frac{\alpha}{2}\right)\left(\frac{\mu_{ctp}^{p}+\mu_{ctp}^{m}}{2}\right)+\left(\frac{\alpha}{2}\right)\left(\frac{\mu_{ctp}^{o}+\mu_{ctp}^{m}}{2}\right)\right)\leq A_{tj}^{e}, \tag{27}
$$

$$
j\in w^{e}, p\in P, t\in T. \tag{28}
$$

Other constraints are the same as constraints (2)–(9) and (12) and (13).

Moreover, in this paper, a correlation method was used to obtain a statistical correlation between two or more random variables. This was done using Statistica software, which allowed calculating the Pearson's correlation coefficient, considered below. First, let us consider the concept of correlation analysis. It refers to a method for processing statistical data that measure the tightness of the relationship between two or more variables. A significant correlation between two random variables always evidences some statistical relationship in a given sample, but this relationship does not necessarily have to be observed for another sample and has a cause-and-effect nature.

To analyze the data and interpret the description of the correlation coefficient values, the data in Table 1 are used.

Let $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ be a sample of n observations of a pair of variables (X, Y). The sample correlation coefficient r is defined as

$$
r=\frac{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)\left(Y_i-\overline{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)^2\sum_{i=1}^{n}\left(Y_i-\overline{Y}\right)^2}}, \tag{29}
$$

where $\overline{X},\overline{Y}$ are the sample averages defined as follows:

$$
\overline{X}=\frac{1}{n}\sum_{i=1}^{n}X_i, \overline{Y}=\frac{1}{n}\sum_{i=1}^{n}Y_i. \tag{30}
$$

Further, based on the above methodology, a statistical analysis of the data provided by the UK governance is carried out. Methods such as induction, deduction, analysis, comparison, generalization, and concretization are also used.

Table 1: The correlation coefficient values and their interpretation [32].

The values of the correlation coefficient r	Interpretation
$0 < \Gamma \leq 0.2$	Very weak correlation
$0.2 < \Gamma \leq 0.5$	Weak correlation
$0.5 < \Gamma \leq 0.7$	Average correlation
$0.7 < \Gamma \leq 0.9$	Strong correlation
$0.9 < \Gamma \leq 1$	Very strong correlation

Table 2: Parameter values of the mathematical model.

fc^{u}_{tj}	Uniform (100,120)	Q^{e}_{j}	Uniform (200,300)
sc_{tj}	Uniform (90,100)	μ_{cpt}	Uniform (120,130)
ic_{tjk}	Uniform (20,30)	l^{p}_{wt}	Uniform (5,12)
oc_{tj}	Uniform (10,15)	$\sigma^{2,t}_{cp}$	Uniform (10,30)
sf_{tj}	Uniform (10,15)	β	Uniform (0.1,0.3)
fo_{wtp}	Uniform (8,12)	θ, β	Uniform (0.1,0.3)
g_{wtp}	Uniform (5,8)	ξ_{0}	Uniform (0.3,0.6)
h^{t}_{wp}	Uniform (6,9)	ξ_{tp}	Uniform (0.2,0.5)
a_{twp}	Uniform (10,15)		

4. Numerical Results

In this section, the efficiency of the multiperiod mathematical model presented in order to redesign the warehouse network is discussed. The required data for the parameters of this problem are generated using a uniform distribution. Table 2 shows the important parameters needed to solve the problem.

Finally, the mathematical model is optimized using GAMS software. It is observed that with increasing the level of satisfaction of the decision-maker, the total cost of the supply chain network should increase. The rate of these changes from 0.1 to 0.5 is very significant, and also, from 0.5 to 0.9, changes in the objective function have small fluctuations. The analysis also shows changes in the cost function versus changes in the weight of inventory and shipping costs. As the share of inventory and shipping costs increases from the total costs, the value of the objective function also increases.

4.1. The Influence of Distribution Systems on Technological Innovation. First, to further analyze changes in the level of innovation activity, consider the intensity of distribution allocated to technological innovations in the concerned area as shown in Figure 2.

Based on the presented data, the maximum intensity of distribution of technological innovations in the period from 2011 to 2020 was reached in 2016, amounting to 6%, while the minimum intensity was 3.9% in 2008 and 2016. Technological innovation activity aims to obtain and apply new knowledge to solve technological and engineering problems, ensuring the production and operation of the enterprise as a single effective complex. It includes changes based on the application of scientific and technological progress, the latest technologies, and management tools.

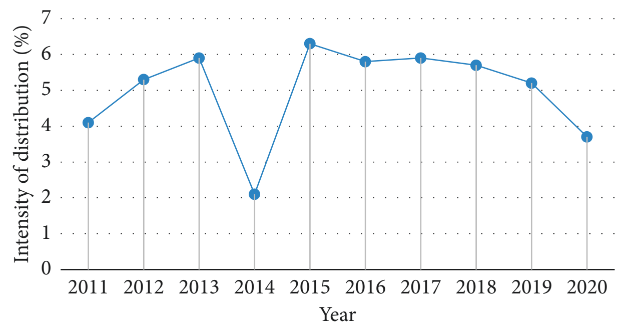

Figure 2: The intensity of expenditures on technological innovations in 2011–2020.

Product innovation activity involves manufacturing products or producing new services or having new characteristics or ways of using them. There are still opportunities to increase the level of product innovation since the proportion of organizations that have implemented innovations remains small.

4.2. Comparison of Implementation Product and Process Innovations on Technological Innovations. An important indicator that characterizes innovation activity is the proportion of organizations that implement product and process innovations. The curves in Figure 3 show these values for the period under review.

The line shows that the maximum percentage of organizations having implemented product innovations for the period under review is 66.7%, reached in 2010. Next, the relationship between the percentage of organizations implementing product innovations and profitability is considered in Table 3.

The correlation analysis has shown that the percentage of supply chain profitability and the intensity of expenditures have an inverse average relationship, indicating that high costs are spent on purchasing and installing new equipment. The inverse relationship is due to the fact that at the beginning of implementation, production decreases and investments increase during the purchase, installation of equipment and personnel training. Further investments are reduced, while the effect of innovation implementation increases because the equipment is installed and running.

4.3. Discussion. During the last two decades, managers have witnessed a period of tremendous global change due to advances in technology, globalization of markets, and new economic and political conditions. With the increase in the number of competitors in the world class, organizations were forced to quickly improve internal processes to remain in the global competition scene. In the 1990s, in parallel with the improvement in production capabilities, industry managers realized that the materials and services received from different suppliers have a significant effect on increasing the organization's capabilities in order to deal with the needs of customers; this, in turn, had a double effect on the organization's focus and supply bases and sourcing

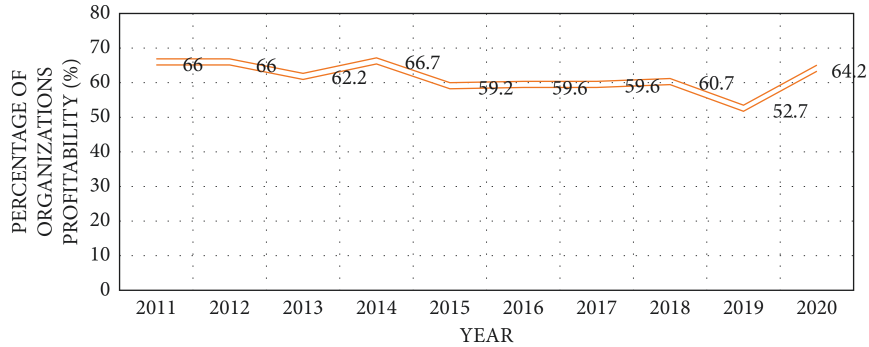

Figure 3: Percentage of organizations having implemented product innovations (%).

Table 3: Correlation analysis of the proportion between supply chain profitability and the intensity of expenditures on technological innovations.

Correlation analysis	
The percentage of supply chain profitability	The intensity of expenditures on technological innovations
66	4.1
66	5.3
62.2	5.9
66.7	2.1
59.2	6.3
59.6	5.8
59.6	5.9
60.7	5.7
52.7	5.2
64.2	3.7
Correlation analysis results	
1.00	−0.51
−0.51	1.00

strategies. Also, the managers realized that it is not enough to produce a product with the right quality. In fact, providing products with the criteria desired by the customer and with the quality and cost desired by them created new management challenges for today's organizations. With such an attitude, the "supply chain" and "supply chain management" approaches came into existence.

The supply chain can be defined as a network of related and interdependent organizations which work together to control, manage, and improve the flow of materials and information from suppliers to end users. The behavior of orders in the supply chain is considered an important issue, which is the main focus of this article. The act of ordering during the supply chain has multiple processes and activities, which indicate the system's efficiency and can be scheduled and require time and resources to perform. Also, the process indicates the performance of the system that causes a logical sequence of activities to realize a predefined goal. A process consists of activities that require resources to be realized. In the process of ordering, orders are made during successive activities that represent the steps required in a certain process. In this regard, the process must be done by spending certain resources and passing through different positions depending on the type of order. It should be noted that the order goes through different routes according to its type. The act of ordering during different stages can have a possible state. When the ordering action is done, its evaluation is done by comparing the goal and the result. As mentioned, the lack of coordination of the result and the goal causes increased costs and loss of customers and the market. This is one of the main challenges in the supply chain. This article seeks to solve this problem or answer this basic challenge. Due to the fact that the ordering process and the arrival of the orders to the final destination are in the form of a queue of orders, the mathematical modeling approach is used to solve the mentioned problem in this article. The presented results show that supply chain optimization can provide comprehensive solutions for managing multiple companies at the same time.

5. Conclusion

The understanding of public service broadcasting, whose main functions are to educate, provide information, and neutrality, has tried to adapt to the competitive conditions brought about by the free market economy on the one hand and to cope with the problems related to financial, technological, and audience demand on the other. Later, it has managed to survive by adopting new accountable features that are pioneers in producing creative, original programs that give importance to the participation of the audience.

In this paper, in order to formulate the role of public demand on distribution systems, a mathematical model is presented to redesign a network of warehouses in a multiperiod, multiproduct model, taking into account the lack of after sales. To date, no studies have been presented to redesign multiperiod, multiproduct supply chain networks, taking into account decisions related to warehouse redesign and lack of backlog. Related decisions include redesigning the chain network, locating new facilities at different strength levels, shutting down nonoptimal existing facilities, expanding the capacity of active facilities over strategic periods, and allocating customers to warehouses. At the same time, decisions related to the optimal economic order quantity for each of the active warehouses in each period have been considered considering the shortage of recovery. Due to the nature of the uncertainty in the parameters of the problem, the uncertainty in the parameters related to the cost and the amount of demand has been considered, and in order to deal with the uncertainties, the Jimenez fuzzy method has been used.

One of the most important managerial insights of this research is that by optimizing the supply chain of urban products, it is possible to have a comprehensive plan for producing and distributing these products in the city. This is despite the fact that the amount of inventory is also managed in different periods, and it is possible to manage the conditions efficiently in emergency situations and when the demand grows sharply.

As a suggestion for future research, we can mention the solution of the proposed mathematical model using meta-heuristic algorithms, modeling the problem by considering routing decisions, and using other uncertainty methods to deal with existing uncertainties.

Data Availability

Data are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Selecting the Optimal LoA to Prevent the Expansion of COVID-19 in the Chemical Industry considering Sustainability Factors: A Fuzzy Mathematical Optimization Approach

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Automation has attracted interest from the industry sector for its potential to improve energy efficiency, cost efficiency, and environmental performance. By elevating the LoA to the highest degree, associated costs will grow accordingly and its implementation will be far more complicated. This will also result in losing workers and decreasing environmental pollutants. On the other hand, increasing power consumption at high levels of automation leads to the production of greenhouse gases. This paper aims to increase the level of automation (LoA) considering the concept of sustainability. This study presents fuzzy multi-objective programming to determine the optimal LoA considering sustainability factors to achieve competitive advantages. To solve the model, the Zimmermann max-min approach was adopted and a cosmetics factory in Iran was chosen to optimize LoA according to this model. The results showed that it is possible to improve the LoA and also consider sustainability factors with the available resources without using the highest LoA. This study can help managers optimize the LoA in their organizations considering the current resources and sustainability issues, and control the company's return on investment and cost of overhead. They can run the model with every definition of LoA proposed till now. This research can benefit the environment and the workers' health in the production line by reducing environmental pollutants and prevent the dismissal of all personnel due to its negative social effects. It also reduces the risk of COVID-19 by minimizing the number of workers. So far, a mathematical model for selecting optimal LoA in the chemical industry considering sustainability has not been presented.

1. Introduction

The high competition among producers and a variety of products has caused organizations to optimize LoA which entails benefits like an increase in quality as well as the production speed, more accurate and faster quality control (QC), a reduction in production waste, better interaction with business systems, an increase in the productivity of industrial units, an increase in the safety factor for manpower and the reduction of mental and physical stress among workers [1].

The implementation of high LoA is a very important issue due to the decrease in dangerous gases emitted from chemical interactions and the transportation hazards of chemicals that threaten the workers in the chemical industry [2]. However, implementing automation at high levels entails heavy expenditure which most organizations cannot afford. Moreover, performing the jobs manually prolongs the production process that in turn increases the chance of infiltration of microbes into the product and can damage the environment and the consumers; therefore, chemical industries can reduce these hazards and the production time by increasing the LoA [3]. Although, at high levels of automation, the number of workers reduces which causes social concerns in the chemical industry. Due to the prevalence of COVID-19 as a pandemic, customer health has become more important than before, and to prevent the risk of this disease, manufacturers are forced to use high LOA in the process of production to prevent endangering the health of customers. It should be mentioned that COVID-19 spreads not only from person to person via close contact respiratory droplet transfer but also on contaminated surfaces. Coronavirus can persist on inanimate surfaces including metal, glass, or plastic for days. Another important reason to increase LoA is to decrease the danger of transferring COVID-19 and avoid transferring viruses to workers and customers. Also implementing optimal LoA can help organizations attain the goals of sustainability. Sustainability is a multifaceted concept. It forces organizations to set goals in three fully interrelated aspects as below:

(i) Providing social responsibility in which the needs of all stakeholders are met;

(ii) Effective protection of the environment and accurate use of natural resources;

(iii) Providing economic growth and economic prosperity.

Few studies have focused on a specific aspect of the problem, such as environmental, social, and economic factors. This separates the model from the real world because these issues need to be considered together. Therefore, the main objective of this research is to determine the optimal LoA for the chemical industry considering three dimensions of sustainability. So the main questions are: What is the optimal LoA in the chemical industry considering the different aspects of sustainability in the chemical industry? Which criteria and parameters should be considered for environmental and social objectives? To answer these questions we developed a bi-objective mathematical model that suggests the optimal LoA considering the concept of sustainability. Also, it keeps some workers in workstations and uses the current budget considering net present value (NAV). The model also reduces pollution in the factory.

(i) The main contribution of this work lies in developing a bi-objective mathematical model that suggests the optimal LoA considering current resources and the concept of sustainability.

The remainder of the paper is as follows. The related literature is reviewed in Section 2 and in Section 3, the problem is discussed. The mathematical model is defined and the objective functions, constraints, and solution approach are described. In Section 4, the implementation of the model is presented, respectively, in an Iranian cosmetics factory. Section 5 provides managerial insights and practical implications. In conclusion, the findings and recommendations for further research are presented in Section 6.

2. Literature Review

2.1. Automation and Autonomy. The term automation was coined in the early 1940s to determine the different mechanisms for the assignment of tasks requiring human monitoring, control, and intervention to automated machines and systems. The degree to which tasks are performed automatically in an industrial or service unit is called levels of automation [4]. The first definition of LoA presented by Sheridan and Verplank [5] defined ten levels of automation for industries. It is based on six activities that humans and systems do in the production process that involves getting, selecting, starting, requesting, approving, and telling. Many other definitions were given till now [6–16]. After that, Riley [17] offered a different definition. He considered a 2-D matrix, in which rows show the levels of automation while the columns correspond to the dimensions of automation. Vagia et al. [18] reviewed all research papers about LoA and developed a new taxonomy. In contrast to a conventional automated system designed to carry out a limited set of preprogrammed supervised tasks on behalf of the user, autonomy is the technology (either hardware or software) designed to carry out a user's goals and does not require supervision [1]. In this sense, successful autonomy is considered to be well designed and highly capable of automation and can adapt to a wider variety of conditions better [19]. This concept is in agreement with Hancock's idea [20] who described autonomy as a later evolution of automation which was historically more restricted in capability and scope than autonomy. Most authors do not differentiate between automation and autonomy but Fereidunian [21] and Parasuraman [14] made a difference between the levels of autonomy and automation. Determining the LoA has a wide range of applications in different industries for example in avionics, teleportation systems, remote control operations, and aircraft control.

In recent research on LOA, Mostafa et al. [22] reviewed 171 research papers and provided a fundamental understanding of adjustable autonomy and its application. Also, Malek [23] considered various definitions of the term automation. His paper aimed at the study, analysis, and discussion of several definitions of the LoA proposed in the literature. On the grounds of this analysis, a set of requirements to be gained by an accurate indicator was given out to propound a new definition of the LoA to be applied in the manufacturing domain to optimize workstations. At the end of this bibliographical study, a table summarizing the list of different definitions and the requirements that each of them meets is drawn. A proposal for a new definition of LoA as a time ratio is also presented. By studying the literature review, we developed a fuzzy multi-objective model that can improve LoA in the chemical industry by considering any one dimensions (1D) or two dimensions (2D) definition of LoA that has been defined before.

2.2. Appropriate LoA. Despite the large benefits of automation, it should be mentioned that the highest LoA is not necessarily the best option and the most appropriate level for many industries; therefore, the optimal LoA for each industry should be determined by considering some issues [5]. The main research for optimizing LoA was done by Frohm [5] that proposed Dynamo's methodology to determine the levels of automation in organizations. This methodology consists of the following stages: planning steps, a preliminary study for identifying activities, documenting the flow of products and activities, identifying the main activity of each production workstation, identifying the sub-activities of each production workstation, measuring the LoA, evaluating the LoA, and analyzing the results. Fasth et al. [9] followed Frohm's research [5] by presenting the Dynamo++ methodology in 12 steps that can measure the current LoA and provide suggestions for increasing the LoA and eventually help the executives to select the optimal LoA. The Dynamo and Dynamo ++ methodologies are time-consuming in terms of implementation and need to simulate the optimal scenario for their implementation. Many types of research are also done using Dynamo and Dynamo++ methodologies: Fasth and Stahre [9] examined six industrial groups that needed to change their automation level and used Dynamo methodology to evaluate the current LoA. In these industrial groups, the main parameter for changing the LoA was the flexibility or production time. They concluded that it is not always necessary to change the LoA. Stahre and Fasth [24] calculated and analyzed the levels of automation in the assembly industry using Dynamo++ in 12 stages so that the best LoA could be determined considering efficiency and cost. The impact of automation on human resources, waste reduction, efficiency, and cost in different industries was investigated in a study by Wang [25], too.

Choe et al. [26] used the Dynamo++ methodology to calculate the LoA in a truck manufacturing factory and simulated the impact of automation on flexibility in the material transportation system. Before this study, the Dynamo methodology was used in assembling systems. Mehta and Subramanian [27] investigated and explored the barriers that a company would face while increasing the LoA in the preassembly production unit. To achieve the primary goal of investigating the barriers, their study took a threefold approach. They measured first the current LoA for the preassembly workstations. This measurement was conducted by incorporating an existing methodology adapted from the Dynamo++ methodology. They concluded that this methodology could be incorporated in measuring and analyzing the current LoA of the preassembly workstations. Hadi and Brillinger [28] declared that achieving high quality and high variety batch size production could be quite expensive. The focus of their research lies on high adaptive and cognitive aspects in the assembly along with qualitative aspects. They presented a level of practical application matrix of all the possible adaptive technologies that were feasible to implement in the preassembly line using Frohm's [5] Dynamo methodology.

By studying the literature review, it can be said that there is no need to use the highest LoA in an organization, and according to the current conditions of organizations in terms of human resources, equipment, and financial resources, the optimal LoA can be selected to suit them. Most research studies show that the used Dynamo methodology is too complex and time-consuming. For this purpose, we have selected the optimal LoA in the desired factory for our case study using mathematical modeling that is user-friendly and can be run fast and considers sustainability. This model has not been used till now.

Recently, some researchers have been done in LoA such as:

Krishnamoorthi [29] demonstrated a methodology for evaluating multiple construction processes and selecting an optimal solution. The methodology combined compositional modeling, case-based reasoning, and stochastic search. Potential solutions consisting of automated construction processes were explored by generating various combinations of process fragments. Malek [30] aimed to propose a new methodology for organizing and identifying the assembly operations that ought to be automated in an automotive assembly line. The different requirements of the methodology were defined, which led to a proposal for a method that respects all the requirements and allows not only the grouping of operations but also the analysis of the automation and the line balancing. Imset Marius [31] studied a drilling unit (MODU) from a subsea oil and gas well. He applied a framework for levels of automation to explore the critical decision process leading to an EQD. He also provided an overview of the benefits and drawbacks of existing automation and decision support systems vs. manual human decision-making. This paper summarizes the growth of Industry 4.0 during the last 5 years and provides a concise background overview of Industry 4.0-related works and its various application areas. Shastri [32] developed a model for Levels of automation for IT services based on Bloom's taxonomy taken as the reference and assessed the automation scope for all the processes of ITIL. Aryal [33] studied heating, ventilation, and air conditioning (HVAC) systems. In this article, he described the development and implementation of an Internet-of-Things (IoT)-based intelligent agent that learns individual occupant comfort requirements and controls the thermal environment using PCS (i.e., a local fan and a heater). The results showed that PCS used improved occupant satisfaction and including some LoA can improve occupant satisfaction further than what is possible with manually operated PCS. Among the levels of automation investigated, inquisitive automation, where the user approves/declines the control actions of the intelligent agent before execution, led to the highest occupant satisfaction with the thermal environment. References [34–37] studied LoA and social impacts on Self-Driving Vehicles.

2.3. Selecting Optimal LoA considering Sustainability Goals: A Research Gap. Usually, Dynamo and Dynamo ++ methodologies have been adopted to select the optimal LoA. The implementation of these methodologies is extremely complex and time-consuming. To the best of our knowledge, no research has ever been conducted to determine the optimal LoA by using a mathematical modeling approach. Also, sustainable development factors (cost, social, and environmental factors) have not yet been considered in selecting the optimal level and dimension of automation. In this study, a mathematical model will be presented to determine the optimal LoA based on both one dimension (1D) and two

Table 1: A review of all research down till now and a research gap.

Writer	Methodology	Case study	Automation	LoA	Cost	Environment	Social
Stayton	Literature review	Self-driving Vehicles	*	*			
Hadi et al.	Dynamo	Industrial groups	*	*			
Fasth et al.(2008)	Dynamo++	Six industrial groups	*	*			
Fasth et al.(2010)	Dynamo++	Assembly industry	*	*	*		
Wang et al.	Dynamo++	different industries	*	*	*		
Choe et al.	Dynamo++	Truck manufacturing factory	*	*			
Mehta et al.	Dynamo++	Preassembly production unit	*	*			
Hadi	Dynamo	Assembly industry	*	*			
Krishnamoorthi	Stochastic Search algorithm	Construction processes	*				
Malek	Literature review	Automotive assembly line	*	*			
Imset Marius	Design a framework	Drilling unit from a subsea oil and gas	*	*			
Shastri	Bloom's taxonomy	IT services	*	*			
Aryal	Heating, ventilation, and air conditioning (HVAC) systems	Implementation an IoT	*	*		*	
Burtnyk, Endsley, FakhrHosseini, Fereidunian, Frohm, Fasth, Frohm, Hancock, Lorenz, Mostafa, Parasuraman, Di Nocera, Sheridan, Simmler, Xu, Vagia	LoA definition	Literature review	*	*			
Frank, abbas, Gopinath, Stayton	Literature review	Self-driving Vehicles	*	*			*
This research	Modeling	Chemical manufacturing	*	*	*	*	*

dimensions (2D) definitions of LoA considering the three dimensions of sustainability. In brief, the research gaps are as follows:

Many studies have focused on a specific aspect of the problem, such as environmental, social, and economic aspects. This separates the model from the real world because these issues need to be considered together;

A large number of studies have used examples generated with random numbers to validate their models, but it is better to validate models using real-world examples and to write models for real case studies;

(ii) There was no research conducted to determine the optimal LoA by using a fuzzy multi-objective model approach.

The goal of this research is to present a mathematical model for selecting the optimal LoA in the chemical industry based on sustainability considerations to reduce the danger of transmitting viruses like COVID-19. The research has been done in the chemical industry in Iran. In Table 1, a review of the LoA has been done and the research gap is shown.

In this study the researchers studied the previous research in LoA optimization, optimized LoA considering sustainable factors with a Fuzzy mathematical optimization approach, defuzzilized the model using LHS, used the Zimmermann max-min approach, conducted a sensitivity analysis (SA) to evaluate the importance of model inputs, and then examined the model in a case study. The differences between this study and the previous studies are as follows. This study optimizes LoA with modeling, considers sustainable factors, and uses a case study.

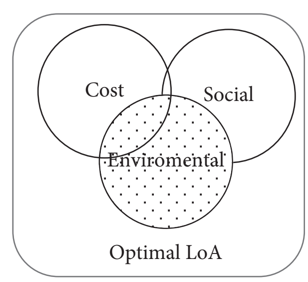

Figure 1: A picture of the problem statement.

3. Problem Statement

During chemical production, if the process of production is long and manually performed, which is usually done at low levels of automation, there is a high probability of infiltration of microbes and viruses like COVID-19 into the product and causing damage to workers and consumers. Consequently, to lessen the level of expected harm chemical manufacturing industries have to reduce the production time by increasing the LoA. It should be mentioned that using full automation has a high cost and most organizations cannot afford it [38]. Full automation

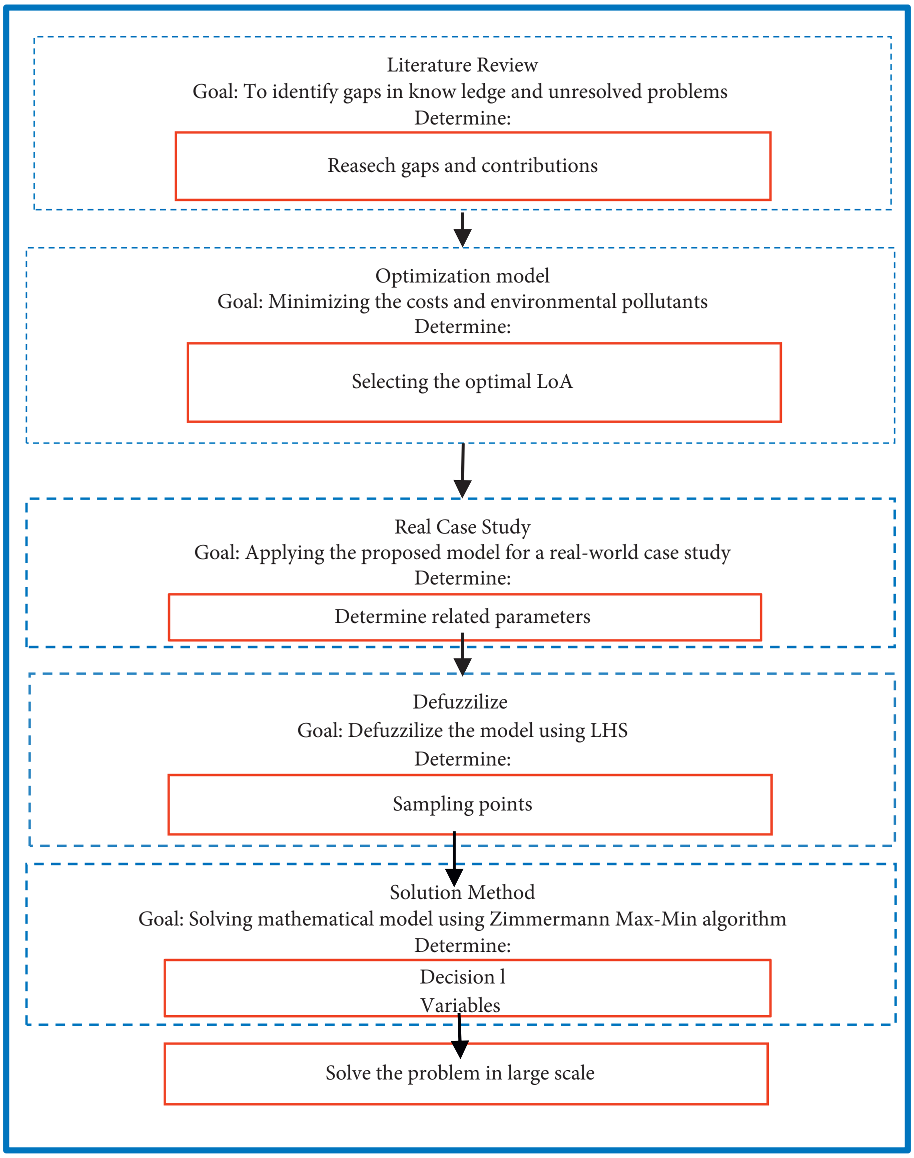

Figure 2: Research framework.

also leads to the downsizing of workers and has negative social effects, consumes more electricity, and produces greenhouse gases. Environmental pollution, in its place, is one of the main problems in society and governmental agencies impose heavy rules and fines for it. There is even a risk of closure of the organization which cannot manage it as well. Taking these issues into account, it is essential to select the optimal LoA in chemical industries by considering the existing financial resources of organizations and maintaining a certain number of workers in production lines which reduces the social damage caused by downsizing the workforce and decreases the environmental pollutants. According to the mentioned issues, the major concern in this research is selecting the optimal LoA in the chemical industry considering sustainability as follows:

Reducing production costs in different production workstations, including the costs of raw materials, labor costs, and overhead costs, maintaining a certain number of production line workers, and reducing environmental pollutants.

A picture of the problem statement is shown in Figure 1.

In this research, first, the literature review is done. The purpose of this section is to determine the research gap. In the second step, a mathematical model is designed. In this model, which was run for a long time, the Net Present Value (NPV) or the current value of cash flows with the desired return rate on the project will be positive relative to the initial capital. Also, the selection of the level and dimension of automation will be measurable with one of the taxonomies. The model applies to all taxonomies of LoA including one-dimensional taxonomy (1D) [39] or two-dimensional (2D) [17]. If the 2D taxonomy is used, the LoA in different dimensions is homogenous; for example, in one dimension it is not fully automatic and in the other dimension it is manual. In this study, the method developed by McKay [40]

Table 2: Parameters, variables, and constants of the model.

Sets	
I	Index of automation dimensions, $i = 1,2,\ldots,$ im
J	Index of automation levels, $j = 1,2,\ldots.,$ jm
F	Index of activities, $f = 1,2,\ldots,$ fm
M	Index of raw materials, $m = 1,2,\ldots$mm
E	Index of the specialists with different skill levels, $e = 1,2,\ldots,$ em
N	Index of environmental pollutants, $n = 1,2,\ldots,$ nm
T	Return on investment period, $t = 1,2,\ldots,$ tm
Parameters	
Upper indexes M, F and P refer to manufacturing workstations, filling workstations, and packaging workstations	
$\tilde{c}_{mt}^{M}$	The unit cost of raw material m in manufacturing workstation M in period t
$\tilde{c}_{mt}^{F}$	The unit cost of raw material m in filling workstation F in period t
$\tilde{c}_{mt}^{P}$	The unit cost of raw material m in packaging workstation P in period t
u_{ijm}	The usage of raw material m at level j and dimensiIn i of LoA
$\tilde{d}_{ft}^{M}$	The overhead costs of activity f in manufacturing workstation M in period t
$\tilde{d}_{ft}^{F}$	The overhead costs of activity f in filling workstation F in period t
$\tilde{d}_{ft}^{P}$	The overhead costs of activity f in packaging workstation P in period t
s_{ije}^{M}	The Number of specialists required with skill level e at the level j and dimensIon i in manufacturing workstation M
s_{ije}^{F}	The Number of specialists required with skill level e at the level j and dimenIion i in filling workstation F
s_{ije}^{P}	The Number of specialists required with skill level e at the level j and dimeIsion i in packaging workstation P
sc_{et}^{M}	The labor cost of each expert with skill level e in manufacturing workstation M in period t
sc_{et}^{F}	The labor cost of each expert with skill level e in filling workstation F in period t
sc_{et}^{P}	The labor cost of each expert with skill level e in packaging workstation P in period t
mb_{ij}^{M}	Total machinery cost in manufacturing workstation M at level j and dimension i
mb_{ij}^{F}	Total machinery cost in filling workstation F at level j and dimension i
mb_{ij}^{P}	Total machinery cost in packaging workstation P at level j and dimension i
λ_{f}^{M}	The number of activities f for production in manufacturing workstation M
λ_{f}^{F}	The number of activities f for production in filling workstation F
λ_{f}^{P}	The number of activities f for production in packaging workstation P
Constants	
pv^{M}	Production volume in manufacturing workstation M (bulk)
pv^{F}	Production volume in filling workstation F (bottle)
pv^{P}	Production volume in packaging workstation P (carton)
b	The change rate of bulk to bottle
p	The change rate of the bottle to carton
d	The difference between the LoAs in different dimensions
$\exp n^{t}$	Environmental impact n in period t
MAXCM	The budget for purchasing machinery
MAXCR	The budget for raw material
MAXCO	The budget for overhead costs
DEMAND	Maximum product demand
NOWCM	The current cost of machinery in manufacturing workstation M
NOWCF	The current cost of machinery in filling workstation F
NOWCP	The current cost of machinery in packaging workstation P
NOWCRM	The current cost of raw materials in manufacturing workstation M
NOWCRF	The current cost of raw materials in filling workstation F
NOWCRP	The current cost of raw materials in packaging workstation P
NOWCSM	The current cost of the specialists in manufacturing workstation M
NOWCSF	The current cost of the specialists in filling workstation F
NOWCSP	The current cost of the specialists in packaging workstation P
NOWCOM	The current labor costs in manufacturing workstation M
NOWCOF	The current labor costs in filling workstation F
NOWCOP	The current labor costs in packaging workstation P
ml	The Number of automation levels permitted to use full automation(without operator)in manufacturing workstation M
fl	The Number of automation levels permitted to use full automation(without operator)in filling workstation F
pl	The Number of automation levels permitted to use full automation(without operator)in packaging workstation P
R_t	Net cash flow in period t
Decision variables	
x_{ij}^{M}	$\begin{cases} 1, & \text{If dimension } i, \text{ level } j \text{ is selected for } LoA \text{ in manufacturing workstation } M, \\ 0, & \text{Otherwise,} \end{cases}$
x_{ij}^{F}	$\begin{cases} 1, & If \text{ dimension } i, \text{ level } j \text{ is selected for } LoA \text{ in filling workstation } F, \\ 0, & \text{Otherwise,} \end{cases}$
x_{ij}^{P}	$\begin{cases} 1, & \text{If dimension } i, \text{ level } j \text{ is selected for } LoA \text{ in packaging workstation } P, \\ 0, & \text{Otherwise,} \end{cases}$

is employed to defuzzilize the model due to its effectiveness and computational efficiency.

Then, a case is stated and in the last step, to solve the mathematical model, the Zimmermann max-min approach is used and the results are analyzed. Finally, a sensitivity analysis (SA) is conducted to evaluate the importance of model inputs. The steps are shown in Figure 2.

3.1. Assumption of the Model

The amount of material consumption in each workstation is specified and predefined, and it is definite in each dimension and for every level of automation in a specific period;

The number of specialists in each workstation is specific, definite, and predefined in each dimension and every LoA;

The cost of materials is uncertain due to changes in exchange rates and world prices;

The cost of specialists and workers in each workstation is certain in each dimension and for every level of automation in a specific period;

(v) Overhead costs are uncertain because they vary in different geographical areas and different seasons;

(vi) The chemical production process includes three workstations-manufacturing, filling, and packaging;

(vii)The model runs for a long time.

3.2. Mathematical Formulation

3.2.1. Notations. The sets, parameters, and variables used in the mathematical model are given as follows (see Table 2):

3.2.2. Objective Functions. The first objective function (1) minimizes all costs associated with the implementation of the automation. Four different costs consist of fixed costs(line one), raw material costs(line two), overhead costs(line three), and labor costs(line four) formulated as follows:

Line one represents the total fixed costs (purchasing machinery) at different levels and different dimensions in manufacturing workstations, filling workstations, and packaging workstations. Line two shows the total cost of raw material at different levels and different dimensions in manufacturing workstations, filling workstations, and packaging workstations.

Line three shows the total overhead costs that are equal to the multiplication of the overhead cost, activity cost driver, and the volume of product at different levels and different dimensions in manufacturing workstations, filling workstations, and packaging. Line four represents the total labor cost at different levels and different dimensions in manufacturing workstations, filling workstations, and packaging workstations. The equation is as follows:

$$Min\left(\begin{array}{c}\sum_{i=1}^{im}\sum_{j=1}^{jm} mb_{ij}^{M}x_{ij}^{M}+\sum_{i=1}^{im}\sum_{j=1}^{jm} mb_{ij}^{F}x_{ij}^{F}+\sum_{i=1}^{im}\sum_{j=1}^{jm} mb_{ij}^{P}x_{ij}^{P}\\ -\left(\left(\sum_{t=1}^{tm}\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{m=1}^{mm} u_{ijm}\widetilde{c}_{mt}^{M}x_{ij}^{M}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{m=1}^{mm} u_{ijm}\widetilde{c}_{mt}^{F}x_{ij}^{F}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{m=1}^{mm} u_{ijm}\widetilde{c}_{mt}^{P}x_{ij}^{P}\right)-\right.\\ \left(\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{f=1}^{fm}\widetilde{d}_{ft}^{M}\lambda_{f}^{M}pv^{M}x_{ij}^{M}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{f=1}^{fm}\widetilde{d}_{ft}^{F}\lambda_{f}^{F}pv^{F}x_{ij}^{F}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{f=1}^{fm}\widetilde{d}_{ft}^{P}\lambda_{f}^{P}pv^{P}x_{ij}^{P}\right)-\\ \left(\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{e=1}^{em} s_{ije}^{M}sc_{et}^{M}x_{ij}^{M}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{e=1}^{em} s_{ije}^{F}sc_{et}^{F}x_{ij}^{F}+\sum_{i=1}^{im}\sum_{j=1}^{jm}\sum_{e=1}^{em} s_{ije}^{P}sc_{et}^{P}x_{ij}^{P}\right)\end{array}\right). \quad (1)$$

In the second objective function (2), the amounts of pollution in the manufacturing workstation, filling workstation, and packaging workstation during the period t are minimized, as can be seen in this equation:

$$\text{Min}\sum_{t=1}^{tm}\sum_{i=1}^{im}\sum_{j=1}^{jm}\left(\left(\sum_{n=1}^{nm} enp_{nt}x_{ij}^{M}\right)+\left(\sum_{n=1}^{nm} enp_{nt}x_{ij}^{F}\right)+\left(\sum_{n=1}^{nm} enp_{nt}x_{ij}^{P}\right)\right). \quad (2)$$

3.2.3. Constraints

$$\sum_{j=1}^{jm} x_{ij}^{M}=1; \quad i=1,2,\ldots,im, \quad (3)$$

$$\sum_{j=1}^{jm} x_{ij}^{F}=1; \quad i=1,2,\ldots,im, \quad (4)$$

$$\sum_{j=1}^{jm} x_{ij}^{P} = 1; \quad i = 1, 2, \ldots, im, \tag{5}$$

$$\sum_{i=1}^{im} \sum_{j=jm}^{jm} x_{ij}^{M} \leq ml, \tag{6}$$

$$\sum_{i=1}^{im} \sum_{j=jm}^{jm} x_{ij}^{F} \leq fl, \tag{7}$$

$$\sum_{i=1}^{im} \sum_{j=jm}^{jm} x_{ij}^{P} \leq pl, \tag{8}$$

$$\sum_{i=1}^{im} \sum_{j=1}^{jm} mb_{ij}^{M} x_{ij}^{M} + \sum_{i=1}^{im} \sum_{j=1}^{jm} mb_{ij}^{F} x_{ij}^{F} + \sum_{i=1}^{im} \sum_{j=1}^{jm} mb_{ij}^{P} x_{ij}^{P} \lesssim MAXCM, \tag{9}$$

$$\sum_{t=1}^{tm} \left(\sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{M} x_{ij}^{M} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{F} x_{ij}^{F} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{P} x_{ij}^{P} \right) \lesssim MAXCR, \tag{10}$$

$$\sum_{t=1}^{tm} \left(\sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{M} \lambda_{f}^{M} pv^{M} x_{ij}^{M} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{F} \lambda_{f}^{F} pv^{F} x_{ij}^{F} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{P} \lambda_{f}^{P} pv^{P} x_{ij}^{P} \right) \lesssim MAXCO, \tag{11}$$

$$pv^{P} \geq \text{DEMAND}, \tag{12}$$

$$pv^{F} = p.pv^{P}, \tag{13}$$

$$pv^{M} = b.pv^{F}, \tag{14}$$

$$\begin{gathered} \sum_{i=1}^{im} \sum_{j=1}^{jm} \left(mb_{ij}^{M} x_{ij}^{M} - \text{NOWCM} \right) + \sum_{i=1}^{im} \sum_{j=1}^{jm} \left(mb_{ij}^{F} x_{ij}^{F} - \text{NOWCF} \right) + \sum_{i=1}^{im} \sum_{j=1}^{jm} \left(mb_{ij}^{P} x_{ij}^{P} - \text{NOWCP} \right) \\ - \sum_{t=1}^{tm} \left[\left(\begin{gathered} \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{M} x_{ij}^{M} - \text{NOWCRM} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{F} x_{ij}^{F} - \text{NOWCRF} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{m=1}^{mm} u_{ijm} \tilde{c}_{mt}^{F} x_{ij}^{F} - \text{NOWCRP} + \\ \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{M} \lambda_{f}^{M} pv^{M} x_{ij}^{M} - \text{NOWCOM} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{F} \lambda_{f}^{F} pv^{F} x_{ij}^{F} - \text{NOWCOF} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{f=1}^{fm} \tilde{d}_{ft}^{P} \lambda_{f}^{P} pv^{P} x_{ij}^{P} - \text{NOWCSP} + \\ \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{e=1}^{em} s_{ije}^{M} sc_{et}^{M} x_{ij}^{M} - \text{NOWCSM} + \sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{e=1}^{em} s_{ije}^{F} sc_{et}^{F} x_{ij}^{F} - \text{NOWCSF} + \frac{\sum_{i=1}^{im} \sum_{j=1}^{jm} \sum_{e=1}^{em} s_{ije}^{P} sc_{et}^{P} x_{ij}^{P} - \text{NOWCSP})]}{(1 + R_t)} \gtrsim 0 \end{gathered} \right.\right. \end{gathered} \tag{15}$$

$$\sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \neq j}}^{jm} \sum_{\substack{i'=1 \\ i' \neq i}}^{im} \left(x_{ij}^{M} \times x_{i'j'}^{M} \right) (j - j') \leq d; \quad j = 1, 2, \ldots, jm \tag{16}$$

$$\begin{gathered} \sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \neq j}}^{jm} \sum_{\substack{i'=1 \\ i' \neq i}}^{im} \left(x_{ij}^{F} \times x_{i'j'}^{F} \right) (j - j') \leq d; \quad j = 1, 2, \ldots, jm \sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j \neq j'}}^{jm} \left(x_{ij}^{F} + x_{ij'}^{F} \right) (j - j') \leq - d + M(1 - Z); \quad j = 1, 2, \ldots, \\ jm \sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j \neq j'}}^{jm} \left(x_{ij}^{F} + x_{ij'}^{F} \right) (j - j') \geq d - MZ; \quad j = 1, 2, \ldots, jm, \end{gathered} \tag{17}$$

$$\sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \neq j}}^{jm} \sum_{\substack{i'=1 \\ i' \neq i}}^{im} \left(x_{ij}^{P} \times x_{i'j'}^{P} \right) (j - j') \leq d; \quad j = 1, 2, \ldots, jm, \tag{18}$$

Table 3: Positive and negative ideal solution.

	Positive ideal solution					Negative ideal solution			
	Z_1	Z_2	……	Z_g		Z_1	Z_2	……	Z_g
Max Z_1	z_1^u	$z_2(x_1)$	…	$z_g(x_1)$	$Min\,Z_1$	z_1^u	$z_2(x_1)$	…	$z_g(x_1)$
Max Z_2	$z_1(x_2)$	z_2^u	….	$z_g(x_2)$	$Min\,Z_2$	$z_1(x_2)$	z_2^l	…	$z_g(x_2)$
……	……	……	……	……	……	……	……	……	……
Max Z_g	$z_1(x_g)$	$z_2(x_g)$	….	z_g^u	$Min\,Z_g$	$z_1(x_g)$	$z_2(x_g)$	….	z_g^l
Best Value	z_1^u	z_2^u	….	z_g^u	Best Value	z_1^l	z_2^l	…	z_g^l

Table 4: The membership function.

For minimization	For maximization
$\mu(g(x))\begin{cases} 1, & if\ Zg(x) \le Z_g^l, \\ 1-(Z_g^u - Zg(x)/Z_g^u - Z_g^l), & if\ Z_g^l < Zg(x) < Z_g^u, \\ 0, & if\ Zg(x) \ge Z_g^u, \end{cases}$	$\mu(g) = \begin{cases} 1, & if\ Zg(x) \ge Z_g^u, \\ 1-(Zg(x) - Z_g^l/Z_g^u - Z_g^l), & if\ Z_g^l < Zg(x) < Z_g^u, \\ 0, & if\ Zg(x) \le Z_g^l, \end{cases}$

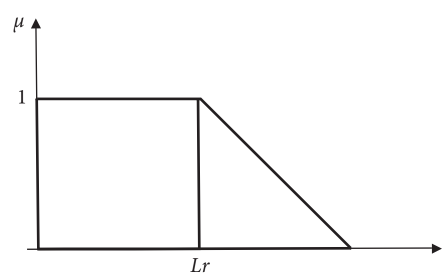

Figure 3: Linear membership function.

$$\sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \ne j}}^{jm} \sum_{\substack{i'=1 \\ i' \ne i}}^{im} \left(x_{ij}^{M} \times x_{i'j'}^{F}\right)(j-j') \le d; \quad j = 1, 2, \ldots, jm, \tag{19}$$

$$\sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \ne j}}^{jm} \sum_{\substack{i'=1 \\ i' \ne i}}^{im} \left(x_{ij}^{M} \times x_{i'j'}^{P}\right)(j-j') \le d; \quad j = 1, 2, \ldots, jm, \tag{20}$$

$$\sum_{i=1}^{im} \sum_{\substack{j'=1 \\ j' \ne j}}^{jm} \sum_{\substack{i'=1 \\ i' \ne i}}^{im} \left(x_{ij}^{F} \times x_{i'j'}^{P}\right)(j-j') \le d; \quad j = 1, 2, \ldots, jm, \tag{21}$$

$$\sum_{i=1}^{im} x_{i1}^{M} = 0; \sum_{i=1}^{im} x_{i1}^{F} = 0; \sum_{i=1}^{im} x_{i1}^{P} = 0, \tag{22}$$

$$x_{ij}^{M}, x_{ij}^{F}, x_{ij}^{P} \in \{0, 1\}; \quad i = 1, 2, \ldots, im; i, j = 1, 2, \ldots, jm. \tag{23}$$

Constraints (3)–(5) ensure that only one LoA can be selected in each dimension in the manufacturing workstation, filling workstation, and packaging workstation. Constrain (7) is introduced to consider social damage and states that the maximum fully automated level (without the operator) in the manufacturing workstation is ml LoA. Constrain (8) is introduced to consider social damage and states that the maximum fully automated level (without the operator) in the manufacturing workstation is fl LoA. Constrain (9) is

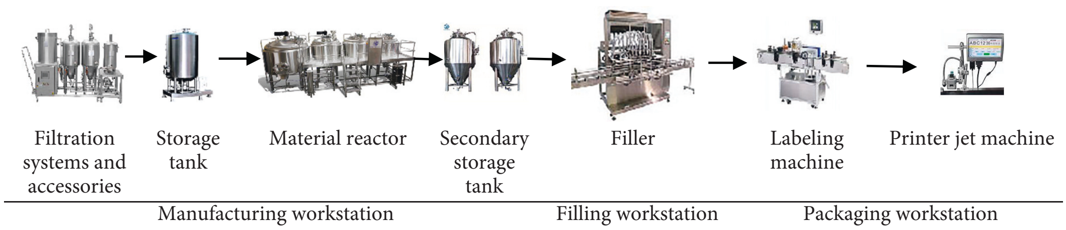

Figure 4: The production process in the cosmetics factory.

introduced to consider social damage and states that the maximum fully automated level (without the operator) in the manufacturing workstation is pl LoA. Constraints (9)–(11) monitor that fixed costs (purchase of machinery) do not exceed the intended budget of the organization (MAXCM), the consumption of raw materials does not exceed the intended budget of the organization (MAXCR), and overhead costs do not exceed the budget of the organization (MAXCO), respectively. Constraint (13) states that market demand should be met. Constraint (14) is the relationship between the number of products in the filling as well as the packaging workstation (i.e., the number of bottles in each carton packaging). Constraint (14) is the relationship between the number of products in the manufacturing and filling workstations (i.e., the amount of bulk used in each bottle that is filled in the filling workstation). Constraint (15) controls the company's return on investment during tm years. Constraints (16)–(18) are to keep the levels of automation in each workstation homogenous in different dimensions. Constraints (19)–(21) are to keep the levels of automation in all workstations homogenous. The difference in the LoA in the three workstations of manufacturing, filling, and packaging should not be great. For example, if the LoA in a manufacturing workstation is high but the LoA in the filling workstation is low, the filling workstation will not respond properly.

Constraint (22) determines that the manual levels in workstations are not allowed. Constraint (23) determines the type of decision variables of the model.

3.3. Solution Approach

3.3.1. Zimmermann Max-Min Approach. To solve the problem, not all goals may be achieved simultaneously under system constraints. In this situation, some tolerance is defined in the model and for this reason, Zimmermann max-min approach [41]is used to solve the bi-objective problem. This method has the following steps:

(1) Start
(2) Solve first and second objective functions separately
(3) Create a pay-off table for the first and second objective functions separately as follows Table 3:
(4) Define the membership function for the first and second objective functions separately Table 4:
(5) Figure 3 shows the linear membership function for minimizing the goal.

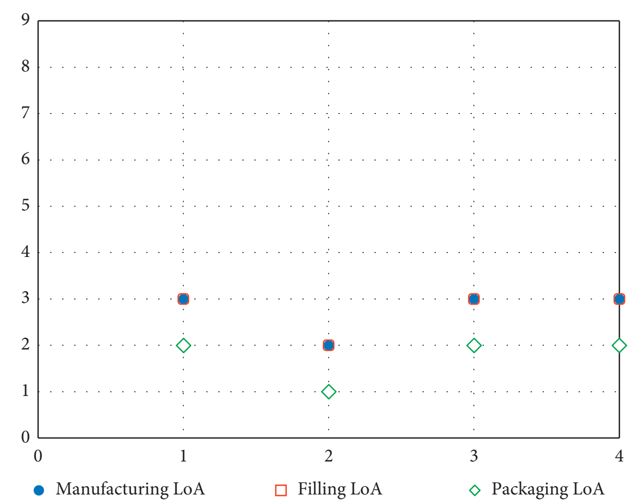

Figure 5: The current LoA in the case study.

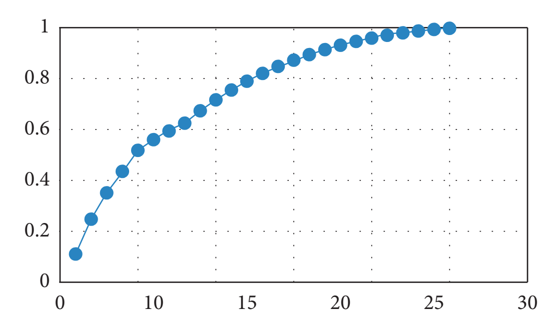

Figure 6: Cumulative distribution of raw materials.

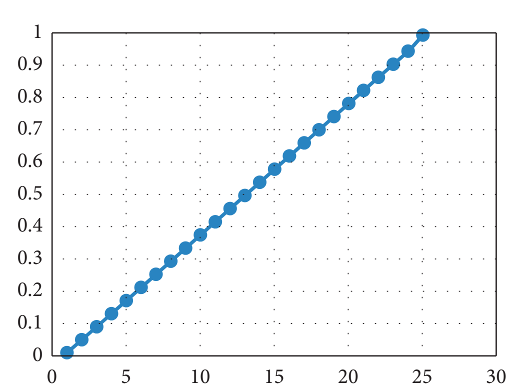

Figure 7: Cumulative distribution of D1, D2.

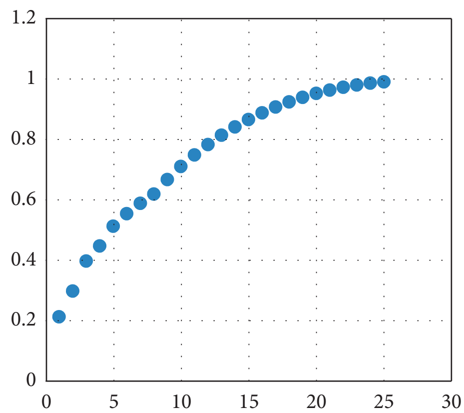

Figure 8: Cumulative distribution of D3, D4.

(6) Transform fuzzy multi-objective linear programming to deterministic linear programming using Latin Hypercube Sampling (LHS).

(7) The new objective function shows the satisfaction level for all objective functions ($Z = Max\lambda$). Then, the membership functions are added to constraints for each objective function as follows:

(8) $\lambda \leq \mu g(x) = Z_g^u - Zg(x)/Z_g^u - Z_g^l$ It should be noted that with the introduction of the Zimmermann max-min and Lp-Metric methods, the introduced multi-objective model becomes a single-objective model. Then, the model was run using the GAMS software on a system with a Corei7 processor.

3.3.2. Lp-Metric Method. In this research, the Lp-metric method has been used to integrate objective functions. In this method, the deviation of the objective functions from their optimal value is considered. At first, the individual answers are calculated for the optimization of each objective function and then the objective function is minimized as follows:

$$\begin{aligned} &\text{Min} \left(\sum_{k=1}^{q} \left[w_k \left| \frac{f*_k - f_k(x)}{f*_k} \right| \right]^p \right)^{1/p}, \\ &s.t. X_\alpha = \left\{ \frac{x}{g(x)} \leq b_h, \quad h = 1, 2, \ldots, g \right\}, \end{aligned} \tag{24}$$

where w_k is the degree of importance for the i-th objective function and $1 \leq p < \infty$ is the parameter defining the Lp-metric method. The value of p determines the degree of emphasis on the existing deviations so that the larger the value of p, the greater the emphasis on the largest deviation. Usually, the values of $p = 1$, $p = 2$, and $p = \infty$ are used in calculations; $p = 1$ indicates that the same importance is considered for all deviations and $p = 2$ indicates that each deviation has its weight so that the largest deviation takes the most weight. When p tends to infinity, the largest deviation indicates distance.

This method is converted to the Min-Max approach for the value $p = \infty$. The variable λ is defined as follows:

$$\lambda = \text{Max} \left(\sum_{k=1}^{q} \left[w_k \left| \frac{f*_k - f_k(x)}{f*_k} \right| \right] \right). \tag{25}$$

Therefore, the multi-objective model can be written as a single-objective model, as to the following relations:

$$\begin{aligned} &\text{Min } Z = \lambda s.t.\lambda \geq w_1 \left| \frac{Z_1 - Z*_1}{Z*_1} \right|, \\ &\lambda \geq w_1 \left| \frac{Z_2 - Z*_2}{Z*_2} \right|, \\ &\lambda \geq w_q \left| \frac{Z_q - Z*_q}{Z*_q} \right|, \\ &X_\alpha = \left\{ \frac{x}{g(x)} \leq b_h, \quad h = 1, 2, \ldots, g \right\}. \end{aligned} \tag{26}$$

4. Results

The case is a cosmetic factory that produces different types of hygienic-chemical products in Iran. The products manufactured at the factory include lipstick, eyeliner, mascara, creams, shampoos, varnishes, powder creams, and other products. Some workstations use a low LoA and employ many workers. However, in the Covid-19 epidemic, the managers have to reduce the number of workers to prevent transmission of the Coronavirus to other workers and customers. Also, due to the costly nature of chemical production and the competitive business environment in this industry concerning the quality level, increasing LoA is very important for reducing the final product's manufacturing costs and increasing the amount and quality of production. But using full automation has a very high cost and its implementation is too complex and time-consuming so the factory cannot perform it. Also, they have to fire many workers and pay a lot of penalties which can result in very negative social effects. On the other hand, it is important to reduce environmental pollutants due to the controls practiced by governmental agencies and the social responsibilities thereof in a way that if the rules are not observed, they will have to pay heavy penalties. Therefore, the aim of implementing the proposed model in this factory is to determine the optimal LoA so that costs and environmental pollution are minimized and several workers are retained with a specific budget. Moreover, in the long run, the Net Present Value (NPV) or the current value of cash flows with the desired return rate on the project will be positive relative to the initial capital. To better understand the content, we examine the production processes as follows:

The production line includes three workstations of production-manufacturing, filling, and packaging. The process flow of cosmetics manufacturing under study is shown in Figure 4.

Proud's definition [15] was used for the implementation of the model. This definition has four dimensions (observe, orient, decide, and act) and eight

Table 5: Best value of Z1, and Z2 in Zimmermann max-min approach.

Scenario	MinZ1		MinZ2		Best Value	
	Z1	Z2	Z1	Z2	Z1	Z2
1	4158692	0.000728049760	4159993	0.000721040600	4158692	0.000721040600
2	4552350	0.000031456810	4557125	0.00003052111	4552350	0.00003052111
3	5558692	0.000001250007	5559123	0.00000101204	5558692	0.00000101204

Table 6: Z and ƛ values were gathered using Zimmermann max-min approach in Scenario 1.

New objective Function	$Z = \text{ma } x^{ƛ}$		ƛ = 0.5
New constraint1	$\lambda \leq (4159993 - z1/4159993 - 4158692)$	SOLUTION	ƛ1 = 0.57
New constraint2	$\lambda \leq (0.000728049760 - z2/0.000728049760 - 0.000721040600)$		ƛ2 = 0.5

LoAs. The LoA in the manufacturing workstation and filling workstation in dimensions observe, decide, and act is 3 and in the orient dimension is 2. The LoA in the packaging workstation in the orient dimension is 2 and in the other dimensions is 3. The current LoA in this factory is shown in Figure 5.

The raw material is added to the reactor in the manufacturing workstation. Unit costs of raw materials in manufacturing workstation, filling workstation, and packaging workstation are fuzzy variables. Also, overhead costs in workstations are fuzzy variables. We considered four overhead costs including the cost of electricity, the cost of water, depreciation cost, and repair cost as D1, D2, D3, and D4.

To deal with uncertainty, the LHS method was used to generate the scenario. Data from the last two years were used and the number of samples was 25 according to Morgan's table. Using the data, a cumulative distribution diagram was drawn and random scenarios were generated using coding in MATLAB as shown in Figures 6–8.

We used the data of three types of specialists who participated in the production processes at different automation levels including simple workers, excellent workers, and specialists. In manufacturing cosmetics, the mixing reactor is regarded as the heart of the process. In this process, the purified and deionized water is transferred into the mixer tank first. Then, the materials are pumped or manually fed into the reactor to be mixed, being simultaneously heated. The amount and duration of heating depend on the process. The next phase is storing the materials in a large container followed by packaging which includes filling, capping, and labeling. The filling machine is a device with at least one tank and a nozzle for filling different bottles. After that, the final phases are packaging and putting the bottles in cartons, which can be performed manually or automatically. It should be noted that in low levels of automation, the workers are present in all production processes, especially packaging and for this reason the risk of transmission of viruses is high. During the manufacturing process, chemical reactions produce several gases including primary pollutants. The pollutants in the cosmetics industry include particulate matter (PM), oxides of carbon, sulfur, nitrogen, ozone, free radicals, and other airborne chemicals like pesticides, chemical sprays, and hydrocarbons. A secondary pollutant is not directly emitted as such but is formed when other

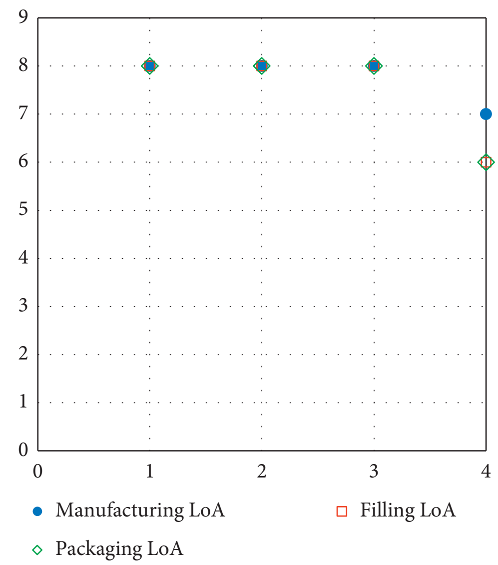

Figure 9: The results of implementing scenario3.

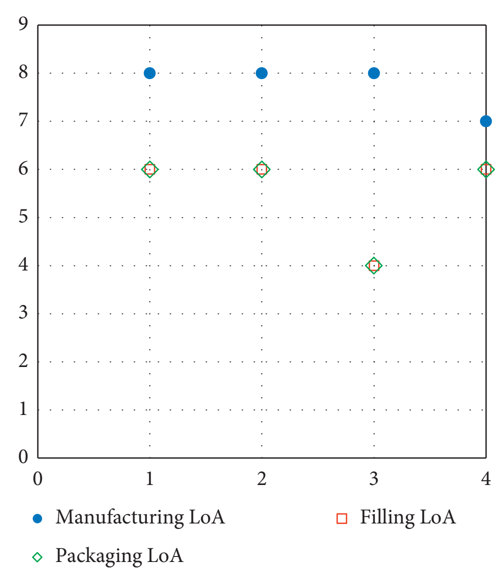

Figure 10: The results of implementing scenario1.

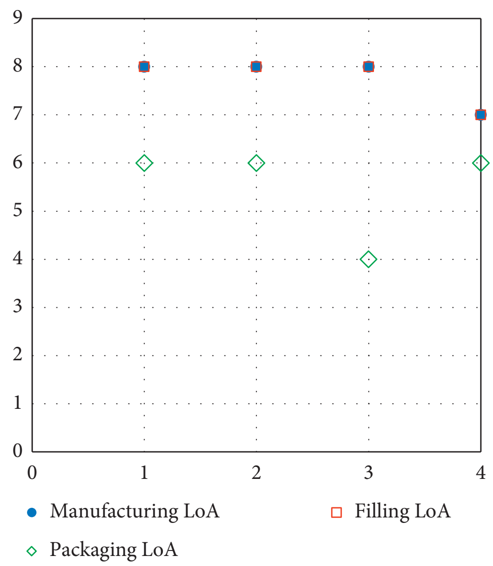

FIGURE 11: The results of implementing scenario2.

pollutants (primary pollutants) react. Examples of secondary pollutants include ozone which is formed when hydrocarbons (HC) and nitrogen oxides (NOx) combine in the presence of sunlight, NO2 which is formed as NO combined with oxygen in the air, and acid rain which is formed when sulfur dioxide or nitrogen oxides react with rain. Another type of pollutant is the sewage made as the result of production processes, the most serious of which include surfactants, detergents, and phosphorus. Major pollutants comprise surfactants, detergents, and phosphorus which are required to be recycled according to environmental standards. In this study, we pay attention to CO2 emissions and greenhouse gases in the production process.

4.1. Discussion. The developed model was coded in GAMS 24.9.2/CPLEX 12.7.1.0 as solver and all cases were run on a computer with a 3.00 GHz processor Intel® core™ i7 processor and 64 GB memory RAM 64 bit. For running the model, three scenarios were selected. The results of implementing various scenarios are presented here:

Scenario 1. The planning horizon is 5 years (tm = 5). The number of workers in the manufacturing workstation is 1 (nm = 1), the number of workers in the filling workstation is 4 (nf = 4), and the number of workers in the packaging workstation is 4 (np = 4). The cost of buying machinery is $ 100,000 ($b = 4$; $p = 6$; $d = 3$).

Scenario 2. The planning horizon is 4 years (tm = 4). The number of workers in the manufacturing workstation is 1 (nm = 1), the number of workers in the filling workstation is 1 (nf = 1), and the number of workers in the packaging workstation is 5 (np = 4). The cost of buying machinery is $ 200,000 ($b = 4$; $p = 6$; $d = 3$).

Scenario 3. The planning horizon is 3 years (tm = 3). The number of workers in the manufacturing workstation is 0 (nm = 0), the number of workers in the filling workstation is 1 (nf = 1), and the number of workers in the packaging workstation is 1 (np = 1). The cost of buying machinery is $ 400,000 ($b = 4$; $p = 6$; $d = 3$).

It can be concluded from the scenario1 that if the organization is not able to pay the costs of purchasing machinery with a high LoA, it can compensate for it by increasing the production level over five years with a low LoA, but the number of production workers will still be really large. In scenario 2, with an increase in investment, the organization will be able to compensate for its costs for four years and some workers are maintained in packaging and filling workstations. On the contrary, in the manufacturing workstation which causes the greatest damage to workers and the environment, there is only one worker in the production lines and the number of pollutants in the environment is relatively low. By reducing the number of workers, we can reduce the danger of the microbial conditional of the product, which results in less damage to the environment. In scenario 3, with an increase in investment compared with scenario 2, the organization will be able to compensate for its costs over three years, and a few workers are maintained in packaging and filling workstations. On the contrary, in the manufacturing workstation that causes the greatest damage to workers and the environment, the completely automated level is used. At the full automated level, there is no worker in production lines and the amount of pollutants in the environment is almost zero. Also, the microbial potential of the product is almost zero and hence there will be no damage to the environment. It is suggested that scenario 3 be used in the factory. This does low damage to the environment and some production workers remain in production lines. It is proportionate to the rich organization's budget. If it is not possible, an increase in the investment amount of scenario 2 is proposed due to the short term of its return on investment. As it is seen, higher fixed costs bring about higher levels of automation with higher profitability and the period of return on investment will be shorter. But, the number of workers is reduced at a high LoA. To prevent social damage caused by downsizing the workers, medium levels of automation are proposed in the packaging workstation because there is no environmental pollution in these lines at lower levels of automation. However, we usually use high levels of automation in the manufacturing workstations because they have beneficial environmental impacts. It must be considered that LoA in different workstations must be homogenous. In running these scenarios, the difference between LoAs in workstations should be less or equal to 4.

The results of implementing scenarios 1, 2, and 3 with the Zimmermann max-min approach in three workstations are given in Tables 5 and 6. In the third scenario, the implementation cost is high, but the amount of environmental pollutants is very low.

Results show that the best scenario is scenario 3. Figure 9 shows that in scenario 3 in the manufacturing workstation in all dimensions the LoA is eight and in the filling workstation and packaging workstation in four dimensions it is seven. In scenarios 1 and 2, the LoA is lower than in scenario 3 and the manufacturing workstation tries to use upper LoA because

Table 7: Detailed results of the implementation of different scenarios.

Scenario	For one day of production (8 hours)							Cost for one product			Profit$	Equipment cost $	Training cost$
	QC time	Break down time	Setup time	Time out	Production time	Production number	No. of workers	Direct material cost $	Labor cost $	overhead costs $			
1. Before the change	4.5	3	0.5	0.5	22	289	10	0.375	0.15	0.1	275	0	0
2. Expert	4.5	2	0.25	0.25	9	326	8	0.3625	0.125	0.075	329	5,000	100
3. Low-cost	4.5	2	0.5	0.5	19.5	714	9	0.375	0.145	0.1	279	1,250	25
4. Costly but profitable	1.5	0	0	0	5	1514	2	0.325	0.0125	0.05	960	250,000	250

Table 8: The data for implementing the three scenarios.

Scenarios	1- Before the change			2- Expert			3- Low-cost			4- Costly but profitable		
	T	P	W	T	P	W	T	P	W	T	P	W
Manufacturing workstation	6.0	64	6	4.0	64	6	6.0	64	6	2.0	64	0.2
Filling workstation	4.0	572	8	2.0	574	6	3.5	572	8	1.0	637	2
Packaging workstation	12.0	550	22	3.0	556	18	10.0	550	22	2.0	635	2
QC workstation	3.0	0	20	1.0	0	20	3.0	0	20	1.0	0	2
Warehouse		530			536			530			631	

T: Time; P: Product quantity; W: Waste quantity

Table 9: The number of experts required in each scenario.

Scenario	The number of experts		
	Simple worker	Excellent worker	Expert
Scenario 1	8	1	0
Scenario 2	5	0	2
Scenario 3	0	0	2

Table 10: Current overhead costs.

Time	Overhead costs: D1			Overhead costs: D2			Overhead costs: D3			Overhead costs: D4		
	Manufacturing	Filling	Packaging	Manufacturing	Filling	Packaging	Manufacturing	Filling	Packaging	Manufacturing	Filling	Packaging
1	450	800	100	300	800	100	22000	17000	12000	22000	17000	12000

Table 11: The result of sensitivity analysis in the scenario1 after changing raw material cost.

Run	Z1	Z2	Increase%	Z1 after change	Z2 after change
1	4158692	0.000721040602	10%-	3382016	0.000721040601
2	4158692	0.000721040601	10%-	3382125	0.000721040602
3	4158692	0.000721040600	10%-	3382126	0.000721040601
4	4158692	0.000721040601	10%	4550578	0.000721040600
5	4158692	0.000721040600	10%	4550569	0.000721040600
6	4158692	0.000721040600	10%	4550592	0.000721040600
7	4158692	0.000721040600	20%	5276520	0.000721040601
8	4158692	0.000721040600	20%	5276516	0.000721040600
9	4158692	0.000721040602	20%	5276520	0.000721040600
10	4158692	0.000721040600	30%	5354012	0.000721040603
11	4158692	0.000721040600	30%	5354016	0.000721040600
12	4158692	0.000721040601	30%	5354012	0.000721040603

of danger in the production process as shown in Figures 9–11.

Table 7 presents the results of the running of the proposed scenarios and the initial state of production. As can be seen, in the costly but profitable scenario, the production time, the amount of waste, and the number of workers in the production line are lower but the production quantity and profitability are significantly higher.

Other results of the implementation of the proposed scenarios are given in Table 8. Table 9 shows that in the low-cost scenario, the production time and the amount of product waste are slightly reduced. In the expert scenario, the amount of waste and the time of production are further reduced. In the costly but profitable scenario, the production time and the amount of waste are significantly reduced. In Figures 12(a,b,c, and d), the variations of production time, the amount of waste, production quantity, and profit in the initial state of production before the change (s0), and the three proposed scenarios (s1, s2, s3) are compared; it was found that the s3 scenario, i.e., costly but profitable, has the least waste, the least productive time, and the maximum profit as shown in Figure 13.

After increasing the number of experts, the results show that the amount of Z1 increases and the LoA decreases. The number of three types of experts is shown in three workstations in Table 9 and Figure 10; the amounts increased and the Z1 value increased, too.

4.2. Sensitivity Analysis. The results show that the amount of Z1 increases after increasing the overhead costs. The results

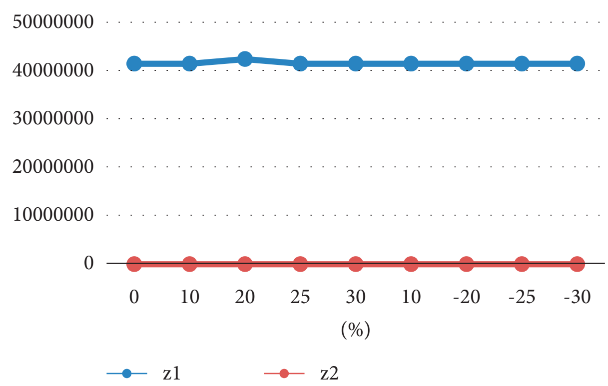

Figure 12: The changes in the overhead costs and a change in Z.

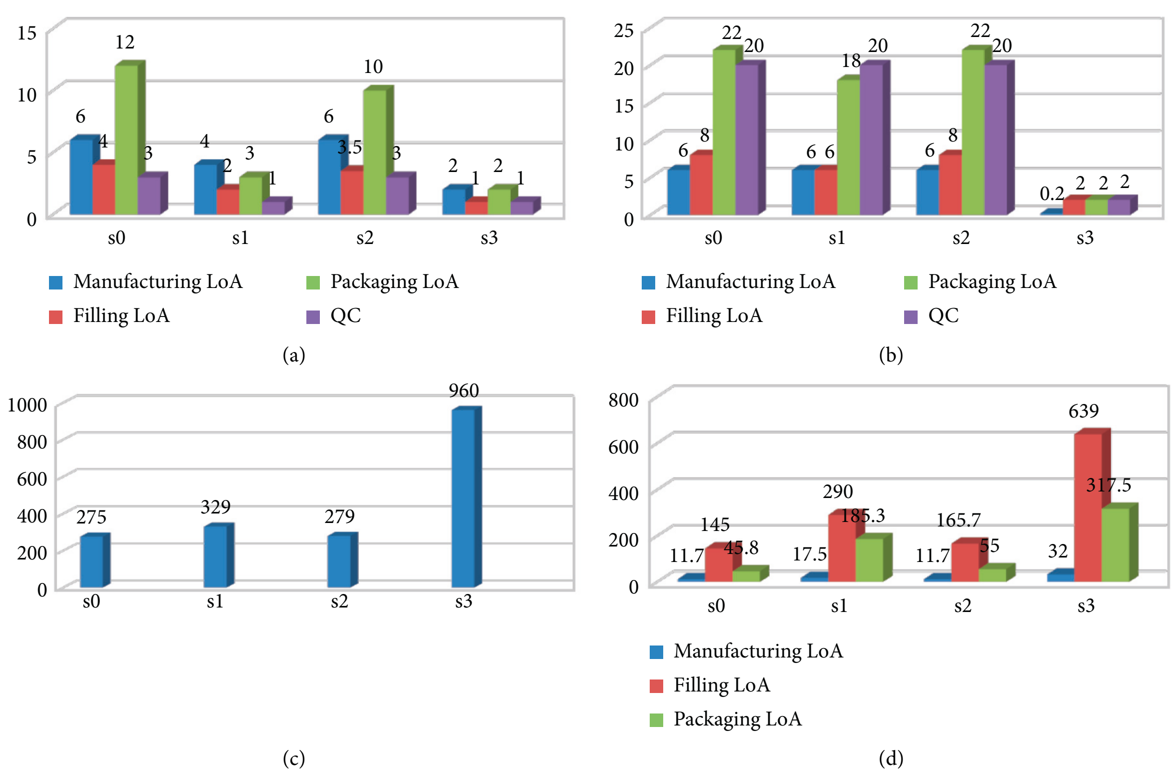

Figure 13: Changes in production parameters after implementing different scenarios s0(Before change), s1(Expert), s2(Low-cost), s3(Costly but profitable) (a) Changes in production time after implementing different scenarios (s0, s1, s2, s3) in the manufacturing, filling, and packaging workstations (b) Changes in production waste after implementing different scenarios (s0, s1, s2, s3) in the manufacturing, filling, packaging, and QC workstations. (c). Changes in profit after implementing different scenarios (s0, s1, s2, s3). (d). Changes in production quantity after implementing different scenarios (s0, s1, s2, s3) in the manufacturing, filling, and packaging workstations.

are shown in Table 10. The results of sensitivity analysis show that increasing the cost of raw materials, the number of workers, and overhead costs leads to an increase in the value of Z1, but it is almost ineffective on the value of Z2 as shown in Table 11 and Figures 12, 14 and 15.

(i) Discussion: The Dynamo method that was previously used to determine the optimal LoA was very complicated and time-consuming, and simulation should be used to implement it, but the model in this research is very practical, simple, and low-cost and it also covers all aspects of sustainability.

5. Managerial Insights and Practical Implications

This model can help executives to select the appropriate level and dimension of automation proportionate to organization resources and requirements. Before optimizing LoA in

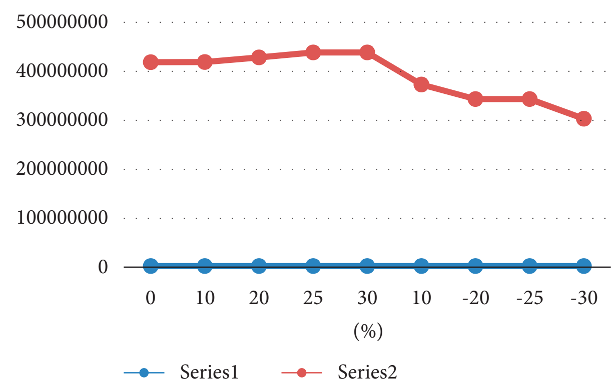

Figure 14: The changes in raw material costs and a change in Z.

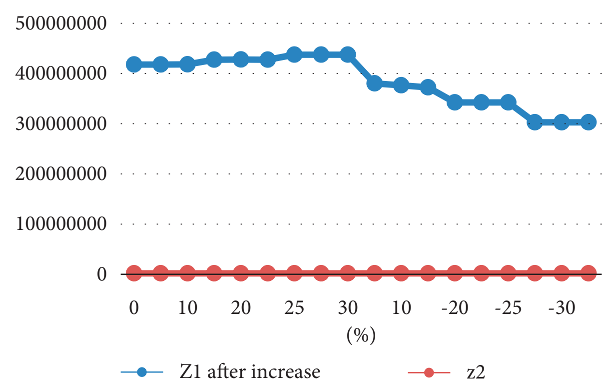

Figure 15: The changes in the labor costs and a change in Z.

chemical industries, the level of environmental pollutants is high and may involve factory closure, heavy penalties, and environmental tax policies. This model helps managers to solve this problem as well. Due to the high cost of full implementation of automation, this model helps managers to create the best performance by choosing the optimal LoA and the dismissal of all workers is also prevented. By using the definition of LoA (2D), it is possible to improve the LoA in different dimensions according to the needs of the organization.

6. Conclusion

In this paper, a mathematical model is developed to determine the optimal LoA in the chemical industry considering triple aspects of sustainability, namely, economic, environmental, and social aspects. The chemical industry process contains three workstations manufacturing, filling, and packaging. Unit costs of raw materials and overhead costs in manufacturing workstations, filling workstations, and packaging workstations are fuzzy variables. The cost of specialists and workers in each workstation is certain.

This research develops a fuzzy multi-objective model that can improve the LoA by considering any one-dimensional (1D) or two-dimensional (2D) definition of LoA. The danger of transactions of COVID-19 is an important reason to increase LoA to avoid virus infection to workers and customers. To achieve these objectives, an organization was asked to consider the existing financial resources and try to maximize the net present value, minimize the environmental damage and maintain a certain number of production line workers to reduce the social damage of downsizing. In our model, NPV should be positive in the long run. By using a two-dimensional definition of LoA, automation levels can be defined in more precise dimensions, such as the definition proposed by Proud et al. [15]. Also, it should be noted that the proposed levels and dimensions of automation should be homogenous; for example, it cannot be completely manual in one dimension and completely automated in another dimension, and it should also be implementable. A bi-objective mathematical model is developed for this purpose. The first objective of the model is to minimize the cost function including the cost of materials, labor cost, and overhead costs, and the second objective is to minimize the number of environmental pollutants. The model is solved using Zimmermann max-min approach. Finally, to validate the model, it is implemented in a real case in Iran and three scenarios are developed to cover the uncertainties that are present in some parameters.

(i) The results show that the optimal LoA can be improved with the available resources and the benefits of increasing the LoA can be used for reducing the social damage caused by downsizing the workforce and decreasing the environmental pollutants.

For further research, the authors can refer to optimizing LoA in other industries and optimizing LoA in the supply chain. They can also consider recycling and optimizing LoA to improve profitability and reduce the related defects. Measuring manufacturing performance parameters can also be measured after improving LoA in organizations.

Data Availability

The data in the article are available in full in the tables.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Identifying and Ranking the Factors Influencing the Performance of Human Resources in Mostazafan Foundation Using Fuzzy Delphi-AHP and BSC Methods

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The presented study evaluates the performance with the balanced scorecard approach and fuzzy Delphi in the Mostazafan Foundation. The main goal of the present study is to consider the most important key indicators of human resource performance for designing a business dashboard based on multi-criteria decision-making in the Mostazafan Foundation. For this, the main contributions of the article are (1) identifying the main effective human resource performance indicators using the Delphi method and (2) presenting an integration framework using multi-criteria decision-making according to the determined indicators. The target population of the study was the senior and middle managers of the Mostazafan Foundation. The questionnaire was completed by 30 experts and Cronbach's coefficient for the questionnaire was calculated to be 0.87. Finally, after using the fuzzy Delphi method, the key indicators for evaluating the performance of the Mostazafan Foundation were obtained and ranked using AHP. The results show the ranking of indicators from the financial perspective: the organization's profit per employee (per capita profit), the organization's income per employee (per capita income), and the cost of compensation for total services per employee; from the customer's point of view: the level of commitment and belonging of employees to the organization; the client's complaint rate and employees' perceptions of using their capabilities in the organization; in terms of internal processes: agility in hiring the right staff, key employees by market standards; and in terms of growth and learning, the percentage of key employees with a development plan, the rate of staff with a coach, and the rate of trained staff.

1. Introduction

Today, many organizations use various tools to measure their performance [1] to stay competitive in their business environment [2]. The indicators that the leaders of the organization have always considered are financial indicators. However, the changing business environment has led organizations to use new performance indicators to be ahead of their competitors in the sea of competition [3]. On the other hand, one of the competitive advantages in organizations is human resources [4]. The management of the human resources unit is considered the main structure of an organization to coordinate the people of the organization to achieve the goals and business strategies set in the organization [5]. From the perspective of management, human resources are the most valuable unique assets of organizations. For this purpose, human resource management pays more attention to people, processes, and technologies within the organization rather than to the external environment. This unit is a pioneer in communicating with people [6]. In this regard, it intends to find ways to improve the performance of the organization. Human resource professionals have responsibilities such as communication management, motivation, and leadership of the organization. In this direction, human resource professionals focus on statistical, computational, quantitative, and strategic aspects of systematic human resource management [7]. Therefore, continuous improvement of organizational performance leads to greater organizational coordination [8]. This coordination can support the growth and development program and create opportunities for organizational excellence [9]. Without reviewing and becoming aware of the progress and achievement of goals, and without identifying the organization's challenges and obtaining information about the implementation of policies, continuous performance improvement will not be possible. All of the above is not possible without measurement and evaluation, so performance appraisal issues can be viewed from different angles [10].

The modern perspective aims at training, growth, and development of evaluated capacities, improving individuals' and organizations' performance, providing consulting services and public participation of stakeholders, and creating motivation and responsibility for improving the quality and optimization of activities and operations [11]. Its basis is to identify the strengths and weaknesses of organizational excellence. The origin of this view is contemporary requirements and develops into a systematic evaluation of performance using modern techniques and methods [12]. The area covered by performance measurement can be the macro level of an organization, a unit, a process, and staff [13]. If the level of performance appraisal includes only individuals, as is common in human resource management, it is done with different criteria in organizations. Although seemingly doing the work, the organization, the individuals, or the organizational unit are only a part of the whole system, and the conditions of other components must also be considered [14]. Paying attention to the organization's all-inclusive criteria and strategies, and aspirations are one of the components of a comprehensive performance management system. Such an approach to performance appraisal will be realistic, equitable, reliable, progressive, and dynamic [15].

The main objective of the present study is, considering the importance of this issue, we seek to find out the most important key indicators of human resource performance for designing a business dashboard based on multi-criteria decision-making in the Mostazafan Foundation. Therefore the main contribution of the article is as follows [16]:

(i) Identifying main effective human resource performance indicators using the Delphi method

(ii) Presenting an integration framework using multi-criteria decision-making according to the determined indicators

The remaining of the article is organized as follows: Section 2 presents literature review and research gap. Section 2 presents problem statement and solution approach. Section 3 presents the main findings of the article and finally, Section 4 presents an overall conclusion and further research for future study.

2. Literature Review

2.1. Review. This section reviewed previous work related to the main subject of this research. For example, Dincer and Hacioglu [17] point out that service companies need to be in a dynamic structure to compete in the business environment. A dynamic structure creates skilled employees and talented managers who work together to develop effective strategies for global competition. The purpose of this study is to investigate the results of banking performance in Turkey based on the level of customer service and satisfaction in services provided using the fuzzy VIKOR approach and hierarchical analysis process method that analyzes the performance of the Bank of Turkey. In order to obtain data dynamics, customer satisfaction competency has been identified as reference point for experts. Findings such as experimental results confirm that the performance results are from different banks in terms of customer satisfaction and types of ownership. The straightforward basic conclusion is about the appropriate facilities of state-owned banks as opposed to private banks. To this end, effective customer service in the performance appraisal process has a strategic role in adopting appropriate competitive strategies. In this research, fuzzy data has been used to analyze the results. Linden [7] states in his research that the business process management system is often focused on controlling flow management. According to resource management, language modeling is mainly based on human resource allocation. At runtime, resource allocation is at the management level. To meet the need for more capabilities in global resource management, this study refers to the integration of interactive dashboards in a resource-aware business process management platform. Together with the appropriate methodology, this framework provides macro perspectives on the right job to increase decision support on human and non-human resource management. Ming et al. [18] presented a new method for evaluating performance and solving complex fuzzy multi-criteria decision-making problems based on a combination of VIKOR and sets of fuzzy numbers with interval values. The problem of performance appraisal often arises in complex implementation processes in which multiple evaluation criteria, theoretical/objective evaluations, and fuzzy conditions must be considered and managed simultaneously. This article forms theoretical, inaccurate, and uncertain processes with the help of linguistic terms in the form of fuzzy numbers, because fuzzy theory can be a suitable tool for working with such uncertain cases. However, presenting linguistic terms in the form of ordinary fuzzy series is not clear enough. Fuzzy number sets with interval values have more flexibility and can better represent the generated vague and ambiguous results and be a more accurate model. This article discusses fuzzy numbers with VIKOR interval values, [19] the purpose of which is to solve multi-criteria decision-making problems. Also, the weight and implementation of various criteria using the concepts of sets of fuzzy numbers have equal interval values. In order to prove the effectiveness of this research method, it has been used to evaluate the performance of the three main intercity bus companies that use the intercity public transportation system. Mohammad and Somayeh [20] have studied the role of balanced scorecard in evaluating the performance of managers of higher education institutions in Bushehr. The performance of higher education institution managers was examined from four aspects of financial indicators, customer retention, internal processes, and the process of growth and learning. The research method was a descriptive survey. Their statistical population was 136 deputies and managers of higher education departments, of which 115 species were randomly selected as a sample in this study. The obtained data were analyzed using SPSS software and statistical method of mean and ANOVA by balanced scorecard. Reference [21] dealt with the impact of implementing a human resource information system on human resource managers' decision-making through the use of business intelligence tools, such as reports, analysis, dashboards, and benchmarks or actions they have paid. In this study, a quantitative methodological approach was conducted based on the results of a survey of 43 CEOs and human resource managers, data analysis methods, correlation coefficient, and regression analysis using SPSS software. The findings of this study provide significant insights into the subject, which show that the information collected by business intelligence tools from the human resources system influences human resource managers' decision-making and the organization's performance. Reference [22], in their research, identified the key indicators that should be used in production dashboards. They also identified other types of indicators. They acknowledged that the dashboard design was different from other display systems. Reference [23] research is to determine whether there is a difference in the field of human resources between domestic and foreign companies in South Africa because companies from developed countries are more successful in this field. Survey responses were collected from 61 domestic companies and 57 foreign companies with more than 200 employees. From the findings, it seems that foreign companies are more involved in having a written mission statement, business strategy, and human resource management, which leads to improved performance in employees and reduced operating costs for such companies compared with local companies. Sirous and Soltanzadeh [10], in their research, presented a quantitative model for evaluating system performance. Their model identifies factors affecting performance and the relationship between them and measures performance by considering relevant factors and a hierarchical analysis process. However, this model has limitations concerning measuring instruments. Irajpour et al. [24] identified and prioritized organizational performance evaluation indicators based on sustainable balanced scorecard methods. Therefore, first, a list of related indicators was extracted using a review of the existing literature and then reviewed by the experts of this company, and the final model was proposed. The results indicate that the flow of liquidity is the priority and the order of air pollution and increasing workforce skills are the following priorities. The proposed model shows that performance indicators can be integrated with different dimensions of stable balanced scorecard using the fuzzy ANP technique. Nekoei Moghadam et al. [25] designed a human resources dashboard. The fuzzy Delphi method and then a mathematical model based on ANFIS (adaptive neural fuzzy inference system) have been used to modify the conceptual model and elements. The statistical sample is the human resources staff of SEPAH Bank, and 132 staff members were selected with Cochran's formula for the classified questionnaire. The questionnaire consisted of 61 questions based on the indicators of the customer and financial perspectives. In the customer model, growth and learning with 0.40 progress have a positive effect on output; the internal process with 0.60 progress shows a positive impact on the output. In the financial model, growth and learning have a negative impact on output with a decrease of 0.29; the internal process shows a negative impact on output with a decrease of 0.14. The results show that the performance for the first output (customer) is 38.80 and for the second output (financial) is 39.00 (in the range of 0–100). The numbers that indicate performance are 50 for the first element and 50 for the second element. Reference [26] stated in their research that today the data sources of multiple companies are large and complex. For this reason, the problem in these organizations is the collection of data that makes it sound at the right time and for the right person whose value is being exploited. To this end, there is a need to analyze the data to provide an overview of the data from the company's raw information, operational, and useful information to help monitor the project and make decisions. In this research, a combination of three business process modules (multiple actors and data sources) has presented a suitable method to support decision-making processes using information technology. The primary purpose of this study is to extract key performance indicators from different data sources and use business techniques, including data visualization techniques and a management dashboard. Moons et al. [27] presented a rigorously defined logistics performance measurement framework to evaluate the efficiency of logistics processes in operating rooms. The analytic network process (ANP) is utilized as a popular multi-criteria decision-making (MCDM) technique to provide effective decision-support models. Modak et al. [28] presented A BSC-ANP approach to organizational outsourcing decision support in the real-world application. In this article, BSC considers elements of decision-making for organizational performance evaluation. Findings show that the proposed approach can help in determining the best outsourcing strategy for an organization. Yang and Lee [29] developed a map strategy for forensic accounting with fraud risk management. For this, consider an integrated balanced scorecard-based decision model. BSC considers elements of decision-making for forensic accounting (FA) measurement. DEMATEL-ANP captures the interrelations in a strategy map for fraud risk management. Finally, the priority significant indicators to promote fraud risk management are selected. Also, a decision model is developed to provide information for FA technology implementation. Abedian et al. [30] determined the best combination of perspective indicators of the balanced scorecard by using game theory. In this article, a mathematical model was employed to determine the equilibrium among the four perspectives of the balanced scorecard (BSC) as four players in a cooperative game to specify the relationship among indicators in the strategy map of Esfahan Steel Complex Company. Huynh et al. [31] created a strategic performance management model for enterprises investing in coastal urban projects toward sustainability. For this, in the article, a strategic management tool was developed by integrating the balanced scorecard (BSC), analytic network process (ANP), and decision-making trial and evaluation laboratory (DEMATEL) methods. Nour et al. [32] verified the impact of applying a balanced scorecard on earnings quality controlled by the Firm (Bank) size of banks listed on the Palestine Exchange during the 2011–2019 period. To achieve this objective, a panel model relating to the dependent variable (earnings quality) and independent variables (balanced scorecard components) with the control variable (Firm size) was estimated. The results showed a statistically [33] significant negative effect of customer perspective (CUS) on earnings quality (EQ); a statistically significant positive effect of internal business process perspective (IBP) on earnings quality (EQ); and a statistically significant positive effect of Firm size (FS) on earnings quality (EQ). Mohammed et al. [34] studied the impact of the management accounting system (MAS) on the circular economy by adopting the agile-adaptive balanced scorecard (AABSC) as a mediating factor for this relationship. The purpose of this study is to recommend the problems of the circular economy represented in waste of resources and air pollution, in addition to innovation, customer satisfaction, and internal operations problems. A dual approach was applied which are structured equation model (PLS-SEM) and artificial neural network (ANN) approach.

2.2. Research Gap. According to the above-mentioned studies, previous research has mostly used prioritization for predetermined indicators. Based on the acquired knowledge, for implementation in an organization, extraction of the index has been done less among experts, because the use of predetermined indicators may not have coordinated with the organization. To overcome this problem, in this research, first, indicators are identified using the Delphi method, then they are prioritized using decision-making methods. In Table 1, previous research literature is categorized.

3. Problem Statement

3.1. Picture of Problem Statement. The study population consisted of experts from senior and middle managers and human resources specialists of the Mostazafan Foundation. According to the required characteristics of experts, including a master's degree or higher or a bachelor's degree with more than 15 years of experience in the Foundation for the Underprivileged, familiar with the balanced scorecard, strategy concepts, and sufficient knowledge of the conditions of the Mostazafan Foundation and its strategies; aware of evaluating organizational performance and key performance indicators; aware of human resource management knowledge; 30 people with this features were identified as a panel of experts. To prepare the literature in the present study, we used library studies including books, articles, journals, research reports, and existing documents. Also, we used the Internet and collected data from a closed questionnaire with a standard scale (validity and reliability). To send and collect data, we applied direct references. In general, in collecting information in the stage of identifying the indicators, three methods such as documentary, Delphi, and survey studies, have been used, and there is a kind of trinity.

In order to collect information, prepare a theoretical framework, study the thoughts and intellectual developments, and different perspectives, the documentary method has been used and referring to all available sources and references. In most multi-criteria decision-making issues, indicators must first be collected and identified. After the initial identification of indicators, using the fuzzy Delphi method and Delphi steps, until the threshold and the collective agreement of experts, the indicators were approved. Experts expressed their agreement through verbal variables such as strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree. In Figure 1, conceptual model of the research is depicted.

To implement the proposed framework, the key indicators of the balanced scorecard dimensions are first determined using regular Delphi meetings with experts. Then, for the second round of Delphi, confidential meetings were held with each of the experts to determine the most important indicators for evaluation [20]. Finally, by determining the indicators, their ranking is done using the AHP.

3.2. Solution Approach

3.2.1. Balanced Scorecard (BSC). A balanced scorecard is a strategy performance management tool, a well-structured report, that can be used by managers to keep track of the execution of activities by the staff within their control and to monitor the consequences arising from these actions [20]. The phrase "balanced scorecard" primarily refers to a performance management report used by a management team, and typically this team is focused on managing the implementation of a strategy or operational activities—in a 2020 survey 88% of respondents reported using balanced scorecard for strategy implementation management, 63% for operational management. Balanced scorecard is also used by individuals to track personal performance, but this is uncommon—only 17% of respondents in the survey use balanced scorecard in this way, however, it is clear from the same survey that a larger proportion (about 30%) use corporate balanced scorecard elements to inform personal goal setting and incentive calculations. The critical characteristics that define a balanced scorecard are [1] as follows:

(i) Its focus on the strategic agenda of the organization/coalition concerned
(ii) A focused set of measurements to monitor performance against objectives
(iii) A mix of financial and nonfinancial data items (originally divided into four "perspectives" as Financial, Customer, Internal Process, and Learning and Growth)
(iv) A portfolio of initiatives designed to impact performance of the measures/objectives

Table 1: Literature categorized.

Author	Solution approach								Set type		Case study
	VIKOR	AHP	BSC	ANP	DEMATEL	GT[1]	ANN	SEM	Certain	Uncertain	
Dincer and Hacioglu [17]	*	*							*		*
Ming et al. [18]	*									*	*
Sirous and Soltanzadeh [20]			*						*		*
Irajpour et al. [24]			*	*					*		*
Moons et al. [27]				*					*		*
Modak et al. [28]			*	*					*		*
Yang and Lee et al. [34]				*	*				*		*
Abedi et al. [1]			*			*			*		*
Mohammed et al. [33]							*	*	*		
In this research		*	*							*	*

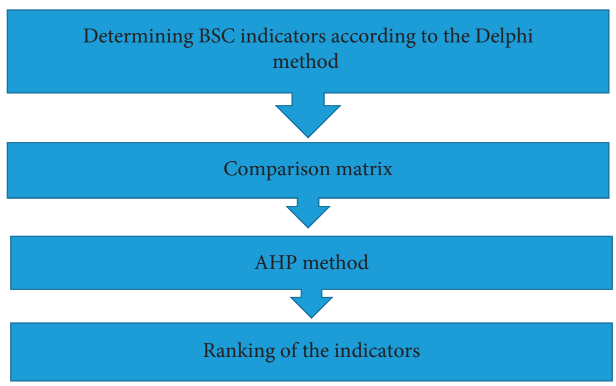

Figure 1: Conceptual model.

Balanced scorecard was initially proposed as a general-purpose performance management system. Subsequently, it was promoted specifically as an approach to strategic performance management. Balanced scorecard has more recently become a key component of structured approaches to corporate strategic management. Two of the ideas that underpin modern balanced scorecard designs concern making it easier to select which data to observe, and ensuring that the choice of data is consistent with the ability of the observer to intervene [27].

3.2.2. Fuzzy Delphi Method. The Delphi method is named after a Greek oracle who had the ability to predict the future. As a research methodology, it was first developed and described in the 1950s with the goal of forecasting and building consensus among a panel of national defense experts who were asked to identify targets in the United States that might be bombed during the Cold War [36]. Researchers needed an alternative to the shortcomings of traditional forecasting methods, such as quantitative modeling and trend extrapolation. Over the past 60 years, the method has been widely applied in business, economics, public policy, and other fields that rely on projections and expert opinions [37].

There is considerable variability in Delphi designs, and many authors fail to fully describe or provide a rationale for their methods. As described in detail below, Delphi designers should be prepared to defend their methodological steps (i.e. processes for protocol development, defining panelists, measuring consensus, and reporting results). Furthermore, methodological decisions should align with any resulting claims. If the Delphi is intended to generate "generalizable knowledge" for consumption by a wide audience, researchers should adopt high levels of rigor and be clear in the reporting of their methodology; however, when used for local consensus building purposes, certain shortcuts might be reasonable [38].

3.2.3. Analytic Hierarchy Process (AHP). Analytic hierarchy process (AHP) is a well-known multi-criteria decision-making (MCDM) method in industries [39]. AHP is based on pairwise comparisons of alternatives and factors [14]. In this article, the weights of the alternatives and then their rank are determined using the AHP method. The steps of the AHP method are described as follows:

(i) Step 1: pairwise comparison matrix

According to the experts' opinions building a pairwise comparison matrix, for alternatives.

$$D_{n\times m} = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nm} \end{bmatrix}. \quad (1)$$

(ii) Step 2: normalized pairwise comparison matrix (**N**)
It is calculated by equation (9).

$$N = \begin{bmatrix} d'_{11} & \cdots & d'_{1n} \\ \vdots & \ddots & \vdots \\ d'_{n1} & \cdots & d'_{nn} \end{bmatrix}, d'_{ij} = \frac{1}{\sum_{i=1}^{j} d_{ij}}. \quad (2)$$

(iii) Step 3: computation of the factor weights.

$$V = \begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix},$$

$$V_j = \frac{\sum_{i=1}^{n} d'_{ji}}{n}, \quad (3)$$

$$V' = NV = \begin{bmatrix} v'_1 \\ \vdots \\ v'_2 \end{bmatrix}.$$

N is the matrix order and V' is the factor weight matrix.

Also, in this study, for AHP considered, a questionnaire was prepared and distributed among experts after identifying the indicators with the Delphi method. The questionnaires are in the form of pairwise comparisons, which are in several levels and according to their higher level, and the experts show the importance of each index with each other in pairs and with numbers between 1 and 9. After that, each index's weighting and the weight of each index were obtained using the analytic hierarchical process.

4. Results

According to the identification of key indicators of human resource performance in four perspectives of the balanced scorecard, we used the approach of analytic hierarchical process and prioritized the key indicators of human resource performance based on the balanced scorecard approach in the Mostazafan Foundation. For this purpose, a pairwise comparison questionnaire was prepared and sent to 30 experts. In the following, we presented the results in each of these scenes.

4.1. Financial View. In this perspective, four criteria of the organization's income per employee (per capita income), the organization's profit per employee (per capita profit), the cost of compensation for total services per employee, and per capita welfare costs are considered. According to the analytic hierarchical process, the relevant criteria were ranked, which are described in Tables 1–3.

In Table 1, we consider the sum of each column and divide each element by it, which is called normalizing the column of the matrix. The results are shown in Table 2.

By normalizing the row of results in Table 3, the weight of each criterion in Table 4 is obtained.

The prioritization of financial perspective indicators is shown in Figure 2.

Based on Table 4 and Figure 2, the priority of key indicators of human resource performance to evaluate the performance of the Mostazafan Foundation in financial view was determined as follows:

(1) Profit of the organization for each employee (per capita profit): 63%
(2) Organization income per employee (per capita income): 22%
(3) Compensation cost of total services for each employee: 8%
(4) Per capita welfare expenditure: 6%

4.2. Customer View. In this perspective, three criteria are considered: the degree of commitment of employees to the organization, employees' perception of using their capabilities in the organization, and the client's complaint rate. According to the analytic hierarchical process, the relevant criteria were ranked. Tables 5–7 are described.

In Table 5, we divide each operation by the sum of the column numbers and normalize the column and the results are provided in Table 6.

By normalizing the row of results in Table 6 and performing the relevant calculations, the final weights of each index were determined and given in Table 7.

The prioritization of customer perspective indicators is shown in Figure 3.

Based on Table 6 and Figure 3, the priority of key performance indicators of human resources to evaluate the performance of the Mostazafan Foundation in the customer perspective were identified as follows:

(1) Employee commitment to the organization: 66%
(2) Employees' perception of using their capabilities in the organization: 65%
(3) Customer complaint rate: 23%

4.3. Internal Processes View. In this perspective, eight criteria were examined, which were: duration of the recruitment process, key staff turnover rate, staff turnover rate, number of HR staff to total employees, number of operational plans implemented to total plans extracted from Human resource strategies, the percentage of adaptation of new employees, agility in hiring qualified personnel, and the distance of compensation for services to market standards.

According to the hierarchical analysis process, the relevant criteria were ranked, which are described in Tables 8–10.

Table 2: Basic table of analytic hierarchical process in financial perspective.

	Per income	Per profit	Per capita welfare costs	Service reimbursement fee
Per income	1	0.2	7	2
Per profit	5	1	9	6
Per capita welfare costs	0.14	0.11	1	1
Service reimbursement fee	0.5	0.16	1	1

Table 3: Normalization table of analytic hierarchical process in financial perspective.

	Per income	Per profit	Per capita welfare costs	Service reimbursement fee
Per income	0.15	0.14	0.39	0.2
Per profit	0.75	0.68	0.5	0.6
Per capita welfare costs	0.02	0.07	0.06	0.1
Service reimbursement fee	0.08	0.11	0.06	0.1

Table 4: Weight of criteria in financial view.

Per income	Per profit	Per capita welfare costs	Service reimbursement fee
0.219	0.633	0.063	0.085

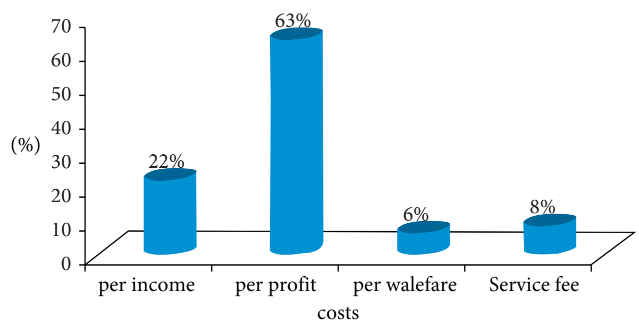

Figure 2: Weight of criteria from financial perspective.

In Table 8, we divide each component by the sum of the column numbers and normalize the column and the results are provided in Table 9.

By normalizing the row of results in Table 9 and performing the relevant calculations, the final weights of each index were determined and given in Table 10.

Prioritization of perspective indicators of internal processes is shown in Figure 4.

Based on Table 10 and Figure 4, the priority of key indicators of human resource performance to evaluate the performance of the Mostazafan Foundation in terms of internal processes was identified as follows:

(1) Agility in hiring qualified personnel 19%

(2) Key employee dismissal rate 18%

(3) Service compensation gap with market standards 17%

(4) Adaptation rate of new employees 15%

(5) Recruitment process time 11%

(6) Number of employees of human resources unit to total employees of the organization 10%

(7) Employee leave rate 6%

(8) Number of operational plans implemented to the total plans extracted from human resource strategies 55%

4.4. Growth and Learning View. In this perspective, the criteria were the attainment of managerial positions (middle managers) by the current employees of the company, the percentage of planned horizontal promotion, the time required to qualify for promotion, the effectiveness of training, per capita training (training hours), trained staff rate, staff rate with a coach, managers who have completed the performance management course, the percentage of key employees with a development plan, and the percentage of development programs implemented, which is given in Table 11 of the experts' opinions according to the results.

In Table 11, we divide each operation by the sum of the column numbers and normalize the column and the results are presented in Table 12.

By normalizing the row of results in Table 12 and performing the relevant calculations, the final weights of each index were determined and given in Table 13.

Table 5: Matrix of pairwise comparisons of criteria in the customer perspective.

	Client complaint rate	Employee commitment and belonging	Employee perception to use capability
Client complaint rate	1	0.25	9
Employee commitment and belonging	4	1	9
Employee perception to use capability	0.11	0.11	1

Table 6: Normalization table of analytic hierarchical process in customer perspective.

	Client complaint rate	Employee commitment and belonging	Employee perception to use capability
Client complaint rate	0.20	0.18	0.47
Employee commitment and belonging	0.78	0.74	0.47
Employee perception to use capability	0.02	0.08	0.05

Table 7: Weights obtained from the hierarchical analysis process in the customer perspective.

Employee perception to use capability	Employee commitment and belonging	Client complaint rate
0.65	0.664	0.23

Prioritization of growth and learning view indicators is shown in Figure 5.

Based on Table 13 and Figure 5, the priority of key indicators of human resource performance to evaluate the performance of the Mostazafan Foundation in terms of growth and learning were identified as follows:

(1) Percentage of key employees with 26% development plan

(2) The rate of employees with a coach is 23%

(3) 11% trained staff rate

(4) Effectiveness of training 9%

(5) Time required to qualify for 8% promotion

(6) Percentage of planned horizontal upgrade 6%

(7) Achieving managerial positions (middle managers) by the current employees of the company 5%

(8) Percentage of implemented development programs 5%

(9) Per capita education (person training hours) 4%

(10) Managers who have completed the performance management course 4%

5. Managerial Insights and Practical Implications

The balanced scorecard model or the balanced evaluation model is a method for turning strategy into action, in other words, this model is a method for operationalizing the ideal, mission, and strategies of organizations, and the company's future perspective is the main area of balanced evaluation model investigations. The balanced scorecard did not have a control role and its criteria are not used to describe past performance, but these criteria are a tool to explain the organization's strategy, which enables the achievement of organizational goals by coordinating activities at various levels of the organization. In this research, factors affecting human resources in the Mostazafan Foundation have been investigated in four dimensions. These four dimensions are Financial view, Customer view, Internal process view, and Growth and learning view. In all four dimensions, while determining the key criteria affecting the performance of human resources, the priority of each of them has been determined by the Mostazafan Foundation. According to the results of ranking the indicators, the first three important indicators in each perspective were listed below.

5.1. Financial Perspective

(i) Profit of the organization for each employee (per capita profit)

(ii) Income of the organization per employee (per capita income)

(iii) The cost of total service compensation for each employee

5.2. Customer Perspective

(i) The degree of commitment and belonging of employees to the organization

(ii) Employees' perception of using their capabilities in the organization

(iii) Client complaint rate

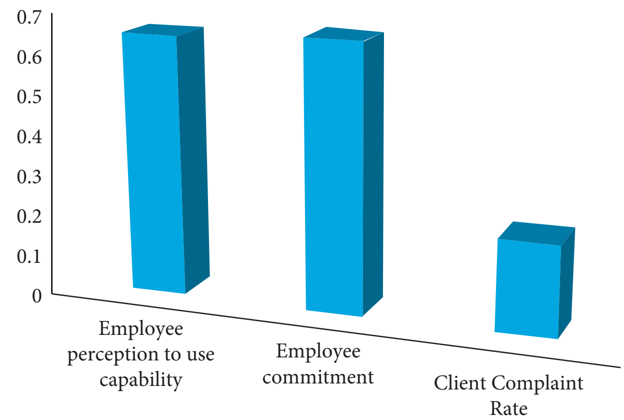

Figure 3: Weight of criteria in the customer perspective.

Table 8: Matrix of pairwise comparisons of criteria in terms of internal processes.

	Duration of the recruitment process	New employee compliance rate	Key staff leave rates	Number of employees of the human resources unit to the total number of employees	Employee leave rate	Service compensation gap with market standards	Agility in hiring the right force	Number of operational plans executed to the total number of programs
Duration of the recruitment process	1	0.2	7	2	7	0.33	0.2	1
New employee compliance rate	5	1	9	6	0.33	0.33	0.2	1
Key staff leave rates	0.14	0.11	1	1	4	7	0.2	9
Number of employees of the human resources unit to the total number of employees	0.5	0.16	1	1	1	0.33	5	1
Employee leave rate	0.14	3	0.25	1	1	0.33	0.2	1
Service compensation gap with market standards	3	3	0.14	3	3	1	3	3
Agility in hiring the right force	5	5	5	0.2	5	0.33	1	5
Number of operational plans executed to the total number of programs	1	1	0.11	1	1	0.33	0.2	1

5.3. Perspectives on Internal Processes

(i) Agility in hiring the right staff

(ii) Drop rate of key employees

(iii) Service compensation gap with market standards

5.4. Perspective of Growth and Learning

(i) Percentage of key employees with a development plan

(ii) Rates of employees with a coach

(iii) Rate of trained staff

Table 9: Normalization table of hierarchical analysis process in terms of internal processes.

	Duration of the recruitment process	New employee compliance rate	Key staff leave rates	Number of employees of the human resources unit to the total number of employees	Employee leave rate	Service compensation gap with market standards	Agility in hiring the right force	Number of operational plans executed to the total number of programs
Duration of the recruitment process	0.06	0.01	0.25	0.13	0.31	0.03	0.02	0.05
New employee compliance rate	0.32	0.07	0.38	0.39	0.01	0.03	0.02	0.05
Key staff leave rates	0.01	0.01	0.04	0.07	0.18	0.7	0.02	0.41
Number of employees of the human resources unit to the total number of employees	0.03	0.01	0.04	0.07	0.04	0.03	0.5	0.05
Employee leave rate	0.01	0.22	0.01	0.07	0.04	0.03	0.02	0.05
Service compensation gap with market standards	0.19	0.22	0.01	0.2	0.13	0.1	0.25	0.14
Agility in hiring the right force	0.32	0.37	0.21	0.01	0.22	0.03	0.1	0.23
Number of operational plans executed to the total number of programs	0.06	0.07	0.00	0.07	0.04	0.03	0.02	0.05

Table 10: Weights obtained from the hierarchical analysis process in terms of internal processes.

Duration of the recruitment process	New employee compliance rate	Key staff leave rates	Number of employees of the human resources unit to the total number of employees	Employee leave rate	Service compensation gap with market standards	Agility in hiring the right force	Number of operational plans executed to the total number of programs
0.115	0.154	0.179	0.097	0.056	0.169	0.187	0.044

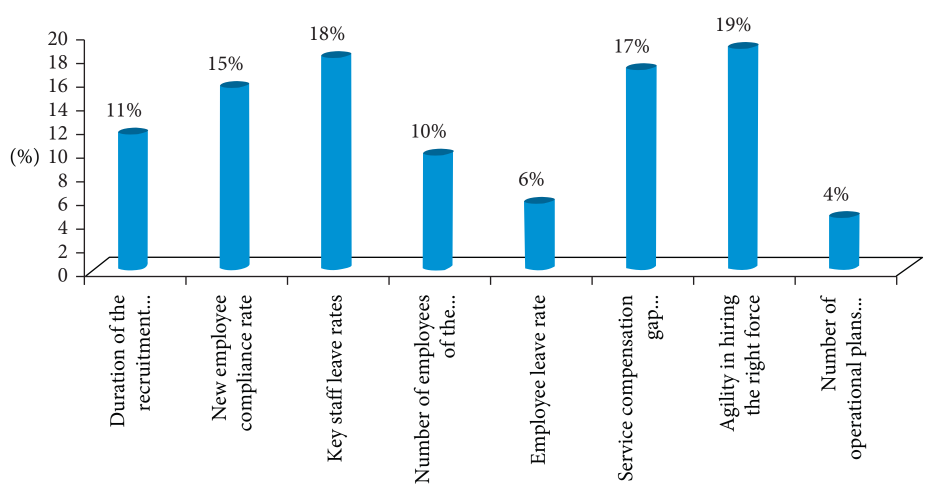

Figure 4: Weight of criteria in terms of internal processes.

TABLE 11: Matrix of pairwise comparisons of criteria in terms of growth and learning.

Criteria	Percentage of development programs implemented	Time required to qualify	Percentage of planned horizontal upgrades	Acquisition of managerial positions by current employees	Managers who have completed a course in performance management	Rates of trained staff	Percentage of key employees with a development plan	Per capita education	Staff rates with a coach	Training effectiveness
Percentage of development programs implemented	1	1	1	3	1	0.33	0.2	1	0.2	0.33
Time required to qualify	1	1	1	4	1	0.33	0.17	1	0.2	5
Percentage of planned horizontal upgrades	1	1	1	6	1	0.33	0.125	1	0.2	0.33
Acquisition of managerial positions by current employees	0.33	0.25	0.17	1	1	0.33	0.2	1	0.2	4
Managers who have completed a course in performance management	1	1	1	1	1	0.33	0.11	1	0.2	0.33
Rates of trained staff	3	3	3	3	3	1	0.33	3	0.33	1
Percentage of key employees with a development plan	5	6	8	5	9	3	1	5	1	3
Per capita education	1	1	1	1	1	0.33	0.2	1	0.2	0.33
Staff rates with a coach	5	5	5	5	5	3	1	5	1	3
Training effectiveness	3	0.2	3	0.25	3	1	0.33	3	0.33	1

Table 12: Normalization table of hierarchical analysis process in terms of growth and learning.

Criteria	Percentage of development programs implemented	Time required to qualify	Percentage of planned horizontal upgrades	Acquisition of managerial positions by current employees	Managers who have completed a course in performance management	Rates of trained staff	Percentage of key employees with a development plan	Per capita education	Staff rates with a coach	Training effectiveness
Percentage of development programs implemented	0.05	0.05	0.04	0.10	0.04	0.03	0.05	0.05	0.05	0.02
Time required to qualify	0.05	0.05	0.04	0.14	0.04	0.03	0.05	0.05	0.05	0.27
Percentage of planned horizontal upgrades	0.05	0.05	0.04	0.21	0.04	0.03	0.03	0.05	0.05	0.02
Acquisition of managerial positions by current employees	0.02	0.01	0.01	0.03	0.04	0.03	0.05	0.05	0.05	0.22
Managers who have completed a course in performance management	0.05	0.05	0.04	0.03	0.04	0.03	0.03	0.05	0.05	0.02
Rates of trained staff	0.14	0.15	0.12	0.10	0.12	0.10	0.09	0.14	0.09	0.05
Percentage of key employees with a development plan	0.23	0.31	0.33	0.17	0.35	0.25	0.27	0.23	0.26	0.16
Per capita education	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.05	0.02
Staff rates with a coach	0.23	0.26	0.21	0.17	0.19	0.25	0.27	0.23	0.26	0.16
Training effectiveness	0.14	0.01	0.12	0.01	0.12	0.10	0.09	0.14	0.09	0.05

Table 13: Weights obtained from the hierarchical analysis process in terms of growth and learning.

Percentage of development programs implemented	Time required to qualify	Percentage of planned horizontal upgrades	Acquisition of managerial positions by current employees	Managers who have completed a course in performance management	Rates of trained staff	Percentage of key employees with a development plan	Per capita education	Staff rates with a coach	Training effectiveness
0.57	0.15	0.14	0.21	0.039	0.73	0.261	0.4	0.229	0.89

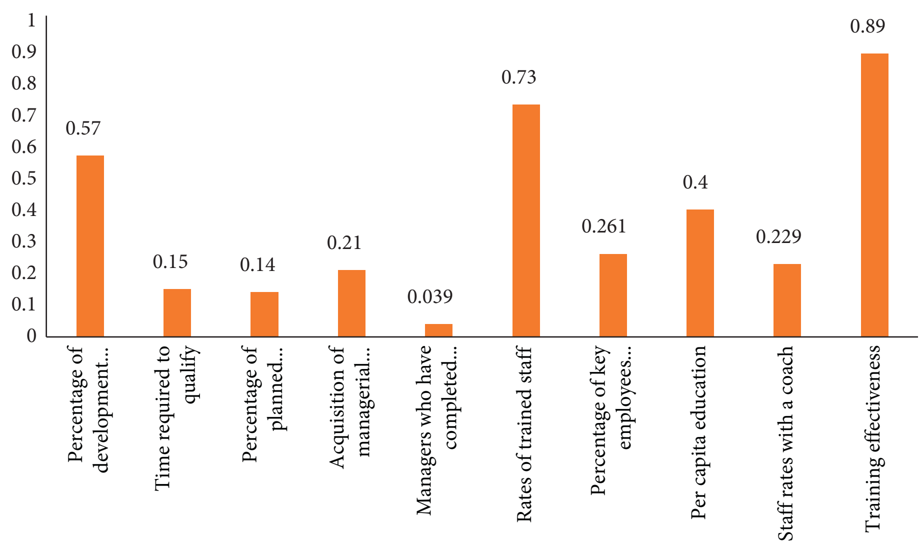

Figure 5: Weight of criteria in terms of growth and learning.

6. Conclusion and Outlook

For this purpose, according to the Analytic Hierarchy Process (AHP), ranking was done in each of the landscapes. According to the results of ranking the indicators, important indicators in each perspective are as follows:

(i) Financial views were determined as follows: (1) profit of the organization for each employee (per capita profit): 63%; (2) organization income per employee (per capita income): 22%; (3) compensation cost of total services for each employee: 8%; and (4) Per capita welfare expenditure: 6%.

(ii) Customer perspectives were identified as follows: (1) employee commitment to the organization: 66%; (2) employees' perception of using their capabilities in the organization: 65%; and (3) Customer complaint rate: 23%.

(iii) Internal processes were identified as follows: (1) agility in hiring qualified personnel: 19%; (2) key employee dismissal rate: 18%; (3) service compensation gap with market standards: 17%; (4) adaptation rate of new employees: 15%; (5) recruitment process time: 11%; (6) number of employees of human resources unit to total employees of the organization: 10%; (7) employee leave rate: 6%; and (8) number of operational plans implemented to the total plans extracted from human resource strategies: 55%.

(iv) Finally, growth and learning were identified as follows: (1) percentage of key employees with 26% development plan; (2) the rate of employees with a coach is 23%; (3) 11% trained staff rate; (4) effectiveness of training 9%; (5) time required to qualify for 8% promotion; (6) percentage of planned horizontal upgrade 6%; (7) achieving managerial positions (middle managers) by the current employees of the company 5%; (8) percentage of implemented development programs 5%; (9) per capita education (person training hours) 4%; and (10) managers who have completed the performance management course 4%.

As it turned out, the "total service reimbursement cost per employee" index has the third priority among financial perspective indicators. This result is in line with decisions related to targeting costs by the organization's senior management. The two indicators of "agility in hiring qualified personnel" and "remuneration gap with market standards" were identified as the most important key indicators of human resource performance in terms of internal processes. This result is in line with the strategic goal of "attracting, retaining, and developing human resources" as one of the two strategic goals of human resources in the Mostazafan Foundation. Also, the index of "key employee leave rate" was among the eight indicators of the perspective of internal processes in the second priority. This result is in line with the policies of the Mostazafan Foundation regarding “leaving the service of key employees” as one of the strategic indicators of the company. It should be noted that in this article, the issue of social responsibility based on Alvani et al. [6] in the context of sustainable development has been studied, which is not mentioned in this article. Suggestion for further research is that it is possible to assess the impact of the considered factors on human resources by using structural equations model.

Data Availability

The data are collected from the real case and are available in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Minimizing OHS Risks with Spherical Fuzzy Sets as a Verdict to Inventory Management: A Case Regarding Energy Companies

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As one of the vital ergonomics operations, occupational health and safety (OHS) measures are important for each and every production environment. Furthermore, the severity of adverse impacts or occurrence probability of OHS risks can be much higher, especially for particular companies dealing with hazardous or dangerous materials or products. Although eminent instances exist in the OHS literature, studies linking OHS to operational supply chain management (SCM) activities and aim to embed ergonomics sentiment into decision procedures in a way that reduces OHS risks are unfortunately lacking in the literature. In this point of view, a novel approach grounding on inventory control aiming OHS risk minimization was developed, and a case study regarding a gas distribution energy company was performed as demonstration. Integrated ABC-VED matrix was developed and employed to handle the inventory management problem by emphasizing OHS risks' influence as well as proposing cost-effective solutions, while spherical fuzzy sets (SFS) and simple additive weighting (SAW) method were used to enlighten the best SCM-related decisions in terms of ABC-VED results, to minimize the OHS risks of maintenance employees and possible adverse impacts on human health. Three different actors participated as decision makers (DMs) by the employment of SFS-SAW group decision making approach, where computed categories and delineated research outcomes were scrutinized in details by benchmarking of the results in terms of varying DM assessments and supplier company driven inventoried item groups, where sensitivity analysis on overall results were also performed. 103 out of 270 items of a protoset were analyzed, a subset of 51 items listed in Category I was determined to be used in further analysis. Illustrative explanations of diversification of criteria weighting scores regarding different parties in the decision making process were also presented with several schematic representations of research outcomes in the light of multidimensional benchmarking debates.

1. Introduction

Ergonomics, or human factors engineering, is defined by International Ergonomic Association [1] as "the scientific discipline concerned with an understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design to optimise human well-being and overall system performance." The origin of the word *ergonomics* goes back to very ancient as it is accepted as a comibation of two Greek words *ergon* and *nomos*, meaning *work* and *laws* [1–3]. Since the fundamentals of ergonomics science ground on providing safe, convenient, and bareable working environment in regards to safety measures and physical health and well-being of employees, occupational health and safety (OHS) is an eminent key in ergonomics applications area for each and every organization performing in all kind of industries. Albeit the advanced measurement methods' and technologically enhanced tools' success, OHS activities are generally focused on the basic control of individuals' behaviours or emerging physical risks related to the environment or job design; which consequence in prosperous achievements in the OHS framework but unfortunately is not able to be sprat into organization-wide through being embedded in management philosophy.

The required components, materials, goods, and services must be provided at the right time, in the right quantity, in the right condition, and at a reasonable price from the right source for each organization; nevertheless, it has more crucial importance for energy companies to continue their operations uninterruptedly and without any immerse impact on human health and life. To obtain this challenging balance is a real quest, where effective business-to-business (B2B) management with their suppliers might be regarded as the main key for success in terms of securing prosperous supply chain management (SCM) operations. Especially for energy companies, who have to purchase varying component parts, products, or raw materials from multiple suppliers operating in many different channels and geographical regions, protecting employees from occupational health and safety (OHS) risks and ensuring that necessary precautions are taken in their interactions with any possible dangerous or hazardous work environment element closely related to the ability to construct and manage the right supply process, as well as identification and implementation of occupational health practices.

In the 21st century, changes in the business environment have contributed to the importance of the B2B relationship management and attracted bigger attention to "supply chain networking." Especially for organizations such as energy companies that need to use a large number of OHS-related products and parts in everyday practices, the management of the channels through which these products are purchased directly determines the OHS levels that can be provided at best.

According to some researchers, supply chain network structures are accepted as new organizational forms under the names of "Keiretsu," "Extended Enterprise," "Virtual Company," "Global Production Network," and "Next Generation Production System" [4]. Regardless of which name is used, companies that want to work with zero error and zero work accidents should plan the procurement, purchase, inventory, and implementation of products, parts, and raw materials that are critical to OHS risks and to cause harm to human health, not only in a cost-effective way but also in a way that minimizes possible OHS risks.

As a part of B2B management and SCM operations, the selection of appropriate suppliers among many suppliers with various potential and competencies is a multicriteria decision-making (MCDM) problem [5]. The complexity of the decision problem will increase with the severity level of the investigated items as with OHS-related matters, and on top of that, numerous conflicting, vague, and challenging criteria will structure the decision space to choose the most appropriate supplier with the aims of reducing purchasing costs along with product delivery time, and simultaneously increasing profits, customer satisfaction, and brand's competitiveness strength.

Inventory management is a systematic approach to the purchase, storage, and sale of raw materials and finished products [6]. Basically, two different main inventory types could be encountered; finished product inventory serves as a substitute for production capacity and can be regarded as stored production capacity, like energy stored in batteries; in contrast, input inventories (raw materials, components, or subassemblies) aim to prevent production inertia and are therefore complementary to production capacity as they increase effective capacity. Regardless of the type of stock in the company, the process should be handled with an effective inventory management approach in-line with organizational targets and strategical goals.

Inventory management approaches indicate scientific ways to designate what to order, when to order, and how much to order, and how much to stock so that purchasing costs and storing costs are kept as low as possible. It helps to protect the organization against the fluctuation in supply and demand, uncertainty, and minimize waiting time [6]. The inventory management process involves monitoring and controlling inventory as it moves from your suppliers to your warehouse and then to your customers, and this particular major SCM problem type receives considerable attention in the related literature. In lieu of this attention, existing research had mostly focused on the financial aspects, where the relation between inventory management and nonfinancial performance of an organization, e.g., its impact on OHS activities remained unclear [7]. However, ergonomics discipline has been studied for a long time and has been practised with successful human factors analysis methods and tools in varying industries to make systems humane, operate smoothly, and increase performance and efficiency levels in many different operational activities; it is a fatal shortcoming of the related existing literature that the necessary link between OHS activities and SCM has not been adequately established in order to take decisions with the effect of ergonomic factors regarding operational SCM activities such as inventory management.

In this study, a novel approach aiming at the elimination or minimization of OHS risks was proposed through inventory control practices in order to simultaneously reduce risks and provide a cost-effective solution ensuring that the company can maintain its competitiveness regarding ergonomics standpoint and SCM management issues without any interruptions or pitfalls in manufacturing and delivery processes. Integrated ABC-VED analysis was employed to determine the item group with utmost relation to cause possible OHS risks and dangers and the highest investment percentages. 103 items out of 270 to be purchased and 197 to be inventoried were categorized, and 51 items were designated to be in Category I into this end. A group decision-making approach was adopted to highlight different perspectives regarding diverse problem space dimensions, as well as, spherical fuzzy sets (SFSs) were used to represent the impact of linguistic judgements and vagueness of the decision problems on the results. After identification of the main items subset and identification of influencing elements, the simple additive weighting (SAW) method was used to further investigate the OHS-SCM problem space as a robust, user-friendly, and potent technique.

In this context, the contribution of this study to the existing literature can be summarized as hereinafter;

(i) OHS risk minimization problem was examined in relation to SCM and inventory management as an attempt to contemplate the influence of human factors strategically from a macro point of view, rather than through tactical applications.

(ii) Risks and uncertainties existing in the decision process were revealed and considered.

(iii) Integrated ABC-VED analysis was introduced and firstly employed for an energy company and OHS-related items as a pioneer study to the related literature.

(iv) SFS was introduced to inventory management literature.

(v) ABC-VED and SFS-SAW methods were used as a first in a study of OHS risk minimization research topic.

(vi) Criteria importance levels representing their influences on B2B relationship management regarding inventory control strategies aiming OHS risk minimization were delineated, and results were benchmarked corresponding to different item groups prior to companies acting in the energy sector.

(vii) Sensitivity analysis was performed with different scenarios to address the robustness of the proposed approach and reliability of the study outcomes.

The remainder of this study is as follows: the surveys performed on the pillars topics of the study were presented under the literature review section. The handled problem was stated, ABC analysis, VED analysis, SFS linguistic terms and mathematical operations, and the proposed approach were introduced under the section of materials and methods. Sensitivity analysis outcomes and obtained results and findings were presented and scrutinized in detail under the results and discussion section, where corollary deductions on the essence of the work were portrayed under the managerial insights and practical implications section. The conclusion section provides the summarization of the study and points out related future research directions in the end.

2. Literature Review

The literature review research related to the pillars of this study was presented under three subsections regarding the studies related to inventory management and inventory control methods and integrated ABC-VED method and applications, studies handling OHS risk assessment and inventory management problems simultaneously, and studies that employed SFS linguistic terms in OHS risk assessment problems.

2.1. Survey of Related Work on Inventory Management and ABC-VED Method. The fundamental factors to be considered decisive in inventory management processes for energy companies are costs and the criticality of the inventoried items [8]. As being the most frequently used inventory management technique in both scholarly researches and field practices, there exist an eminent and immense number of studies of inventory management problems carried out with the ABC method. From this standpoint, introducing existing instances on the basis of application fields or the methods in which they are used together might provide a more understandable and easy-to-follow presentation, and be in the interest of the readers. As examples of recent studies, Partovi and Anandarajan [9] and Banharnsakun [10] employed the artificial neural network (ANN) method for upgrading ABC classification, Ramanathan [11] proposed a novel weighted linear optimization model, where Nallusamy et al. [12] employed more traditional approaches such as MRP techniques, quantity-based discounts methods, or classical optimization models. There are some studies that employed MCDM techniques with ABC analysis, for instance, Simunovic et al. [13] and Kabir and Hasin [14] compared several inventory classification models with analytical hierarchy process (AHP) method and AHP-TOPSIS methods, respectively. With similar approaches and applications, Gupta and Kant [15], Devnani et al. [16], Gupta et al. [17], Vaz et al. [18], Devnani et al. [19], Anand et al. [6], Mahatme et al. [20], Wandalkar et al. [21], Pirankar et al. [22], Kumar and Chakravarty [8], Singh et al. [23], Antonoglou et al. [24], Ceylan and Bulkan [25], and Durmuş and Duğral [26] employed ABC and VED analysis integrally.

Among various selective inventory control techniques such as EOQ (economic order quantity) [8, 16–18, 20–34], VED (vital, essential, desirable) [6, 8, 17–19, 21–25, 35–37], FSN (fast-moving, slow-moving, non-moving) [30, 37, 38], SDE (scarce, difficult-to-procure, easily-available) [39], XYZ [32], safety stock (SS) [39], vendor-managed-inventory (VMI) [38, 40], and reorder point (ROP) [39] methods, each organization should manage this process by applying one or more stock control methods in accordance with the operating market and core- and side-activities to be carried out. Since the integrated computation matrix considers both the critical values and the economic and importance levels of items, the integrated ABC-VED analysis is the most frequently used method to address the optimal budget regarding the criticality levels and required amounts [6, 8, 15–22, 27, 29–35, 37, 41–44].

As the integrated ABC-VED analysis allows practitioners to ensure critical items and never go out of stock on those while minimizing the costs, this method found a very particular audience in health practices and has acquired a very wide application area in the related literature regarding drug center, pharmacy, and hospital management problems [4–36, 39, 41].

2.2. Survey of Related Work on OHS and Inventory Management. Although OHS and inventory management issues are in close interaction with each other, the current literature is far from meeting the need in this regard when the number of studies on the subject and the scope of these studies were considered.

As one of the scarce instances, Fan and Zhou [7] underlined the connection between OHS performance and the supply-demand mismatch of an organization. They developed an approach grounding on the normal accident theory (NAT) and return-on-assets (ROAs) method to investigate productivity pressure on safety issues, and practised a case study for textile manufacturers. The authors analyzed the correlation between supply-demand mismatch levels and a higher likelihood of safety incidents; a more salient impact was found regarding more complex (labor intensive) and tightly coupled (high production capacity utilization) operation environments.

The other instance of this topic handled an inventory management system articulation. Crouse et al. [45] designed an online barcode-based inventory control and tracking system for a chemical industry company to be able to track hazardous items and employees to be engaged with them more accurately and efficiently, as well as, suggesting a waste management system for the hazardous materials operating on the developed inventory management system.

As for the entailed research methods, although its vast application in so many valuable researches on health management-related decision problems, the ABC-VED method has not been used in decisions related to OHS management, or has not been employed in a study with OHS risks minimization aims, to the best of our knowledge. This occasion addresses a serious gap in the current literature that needs to be closed quickly, since this particularly suitable method for companies is attaining more attention than any other one to its activities related to OHS, i.e., energy companies have not been used yet in such a case study regarding the inventory process management of highly critical items to OHS-related risk and dangerous occurrences.

2.3. Survey of Related Work on OHS and SFS Applications. As a relatively new method, the application examples of SFS linguistic terms in problems related to OHS topics are also limited. The existing research instances employed SFS with anMCDM method to embrace the verbal judgements and accurately represent the assessments of decision makers (DMs) at best.

Sharaf and Khalil [46] employed the TOmada de Decisão Interativa e Multicritério (TODIM) method with SFS to the supplier selection problem. The authors practised a case study on selecting green OHS equipment suppliers with the SFS-TODIM method, and subsequently used the Technique of Order Preference by Similarity to an Ideal Solution (TOPSIS) and the VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) methods with SFS to compare the computation outcomes and examine the effect of the attenuation factor of losses on the solution.

In another example, Liu et al. [47] developed an OHS risk assessment framework by integrating the TODIM and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods with SFS, and determined the priorities related to the identified OHS hazards for medical staff of a hospital.

2.4. Research Gap. As a result of the performed literature review, surveys on the study pillar topics are classified and presented to the readers in Table1, hereinafter.

As Table 1 indicates, there is an explicit need to make a connection between OHS risk minimization and inventory management topics in the related literature. Most of the existing inventory management studies employed ABC-VED integrated matrices with cost minimization and deficiency prevention objectives for critical items, whereas any existing study performed on inventory management topic did not focus on OHS risk minimization to the best of our knowledge neither with the integrated ABC-VED method nor any other inventory management techniques. There are two studies which were focused on the relationship between OHS safety levels and SCM activities through supplier selection problem considering OHS equipment employing SFS to represent the vagueness of the problem, where none of them employed the SFS-SAW method as MCDM techniques as well as both did not investigate the relationship between inventory management activities and supplier selection decisions, hence did not perform an additional study to this end and did not predicate the latter decision problem's input data into that results. Furthermore, where the integrated ABC-VED method was frequently used especially in health-care related industries and application areas, surprisingly, surveys indicated that it has never been used in the energy industries to the best of our knowledge, while the risk of occupational accidents in this industry is very high and the possible consequences could be very destructive.

As a consequence, studies focusing on the relationship between ergonomic OHS risk minimization and SCM inventory control and tracking topics would help to enrich the existing literature and shed light on scientific researchers, ergonomists, and field practitioners interested in OHS activities, inventory management, human factors engineering, and SCM. This study aims to close the abovementioned major gaps of the related literature, while it suggests new application instances of an SFS-MCDM method and managerial strategies developed upon the obtained computation results and sensitivity analysis for a pristine application area, the energy industry.

3. Materials and Methods

3.1. Problem Statement. A novel integrated approach was proposed for handling the OHS risk minimization problem within this study. This novel approach firstly applies an integrated ABC-VED analysis to be able to ensure taking into account the severity levels of the necessary items in order to eliminate or minimize the OHS risks, in the meantime, the cost factors were not ignored to ensure organizational survival, through handling the inventory management problem, then, the integrated SFS-SAW method was used to efficiently manage the uncertainty existing in the decision process and determine the importance and performance levels related to the decision parameters. Furthermore, obtained results were further investigated subsequently and sensitivity analyses were performed, and grounding on the outcomes of these solution elicitation operations OHS risk minimization strategies were developed through a B2B relationship management perspective for the group that should be followed closely among the listed inventoried items. The general illustration of the operation flow of the proposed approach is represented in Figure 1.

The consecutive stages of the proposed approach, computation substeps and activities, and general operation mechanism of the proposed approach were explained later in this section with their finest details, where the schematic representation of the investigated system and developed solution approach are also presented in Figure 2, so that the

Table 1: Classification of literature survey summary.

Reference	Problem content			Objective	Methodologies			Case study
	Inv. Man.	OHS	Uncertainty		Inventory management	MCDM	Other	
Crouse et al. [45]	✓	✓	—	Safety and waste	—	—	Barcode based tracking system	Chemical industry
Gupta and Kant [15]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Thawani et al. [27]	✓	—	—	Cost and criticality	ABC-VED, EOQ	—	—	Drug store
Gupta et al. [17]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Vaz et al. [18]	✓	—	—	Cost	ABC-VED	—	—	Hospital
Devnani et al. [16]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Nigah et al. (2010)	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Mahatme et al. [20]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Anand et al. [6]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Wandalkar et al. [21]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Borle et al. [28]	✓	—	—	Cost and criticality	ABC-VED, EOQ	—	—	Drug store
Ben Hmida et al. [30]	✓	—	—	Cost and criticality	ABC, VED, FSN	—	—	Oilfield equipment industry
Pirankar et al. [22]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Singh et al. [23]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Stoll et al. [31]	✓	—	—	Criticality	ABC-VED, XYZ	AHP	—	Manufacturing industry
Kumar and Chakravarty [8]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Kant et al. [32]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Gupta and Krishnappa [33]	✓	—	—	Cost and criticality	ABC-VED	—	—	Dental hospital
Antonoglou et al. [24]	✓	—	—	Cost and criticality	ABC-VED	—	—	Military hospital
Ceylan and Bulkan [25]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Subratha et al. [34]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Fakhrzad and Lotfi [38]	✓	—	✓	Time, cost, quality and environment	VMI	—	Mixed integer linear programming	Hospital
Fan and Zhou [7]	✓	✓	—	Safety	—	—	NAT-ROA	Textile industry
Hazrati et al. [35]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Hussain et al. [41]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital
Mishra and Mohanty [37]	✓	—	—	Cost and criticality	ABC, VED, FSN	—	—	Numerical example
Sharaf and Khalil [46]	—	✓	✓	Importance and performance	—	TODIM, VIKOR, TOPSIS	SFS	Numerical example
Pholpipattanaphong and Ramingwong [39]	✓	—	—	Cost and criticality	ABC-VED, EOQ, SS, ROP	—	—	Hospital pharmacy

Table 1: Continued.

Reference	Problem content: Inv. Man.	Problem content: OHS	Problem content: Uncertainty	Objective	Methodologies: Inventory management	Methodologies: MCDM	Methodologies: Other	Case study
Prommarat and Santiteerakul [42]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Mor et al. [43]	✓	—	—	Cost and criticality	ABC-VED	—	—	Manufacturing industry
Liu et al. [47]	—	✓	✓	Risk assessment	—	TODIM, PROMETHEE	SFS	Hospital
Durmuş and Duğral [26]	✓	—	—	Cost	ABC-VED	—	—	Hospital
Gizaw and Jemal [36]	✓	—	—	Cost and criticality	ABC-VED, FSN	—	—	Drug store
Annie et al. [29]	✓	—	—	Cost	ABC-VED, EOQ	—	—	Food industry
Atakay et al. [44]	✓	—	—	Cost and criticality	ABC-VED	AHP	OptQuest—ARENA	Automotive industry
Lotfi et al. [40]	✓	—	✓	Cost	VMI	—	Non-linear programming	Hospital
Singh et al. (2022)	✓	—	—	Cost and criticality	—	—	—	Literature review
This research	✓	✓	✓	Cost, criticality, safety and performance	ABC-VED	SAW	SFS	Energy industry

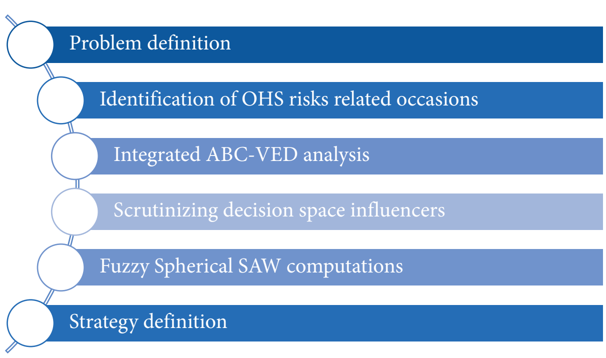

Figure 1: General operation flow of the proposed approach.

readers can better understand the implementation mechanism and interaction with the decision environment of the proposed novel approach.

The company carries out its current SCM operational management (OM) activities solely in regards to the experience of DMs and cost-effective solutions, where this situation often could result in the emergence of OHS risks and hazards in lieu of high deficiency ratios or late delivery than declared lead times of purchased items. The proposed approach aims to provide DMs with competent and effective solutions in practice through simultaneously considering OHS risk minimization, various conflicting factors affecting the decision problem, and the uncertainties to improve the existing OHS, SCM, and OM processes.

As another gaining targeted to be yielded, the proposed approach employs the group decision-making method, and sensitivity analyses reflecting the influence of diverse perspectives on the solution space dimensions were also performed with six different scenarios.

3.2. Notation List

3.2.1. Sets (Indices)

i: Index of inventory item $i \in I = (1, 2, \ldots, i)$

j: Index of supplier $j \in J = (1, 2, \ldots, m)$

t: Index of scenario $t \in T = (1, 2, \ldots, t)$

f: Index of run $f \in F = (1, 2, \ldots, f)$

e: Index of calculation universes $e \in E = (1, 2)$

q: Index of elements of pth spherical fuzzy set $q \in Q = (u, r)$

p: Index of spherical fuzzy sets $p \in P = (A, B)$

d: Index of DMs $d \in D = (1, 2, \ldots, d)$

k: Index of criteria $k \in K = (1, 2, \ldots, n)$.

3.2.2. Parameters

E_e: calculation universe e

P: spherical fuzzy set P

$\mu_{\tilde{A}_s}(u)$: the membership function value of element q to spherical fuzzy set P

$\nu_{\tilde{A}_s}(u)$: the nonmembership function value of element q to spherical fuzzy set P

$\pi_{\tilde{A}_s}(u)$: the hesitancy degree of element q to spherical fuzzy set P

k: scalar value

$S(\tilde{w}_k)$: the spherical weighted importance value of criteria k

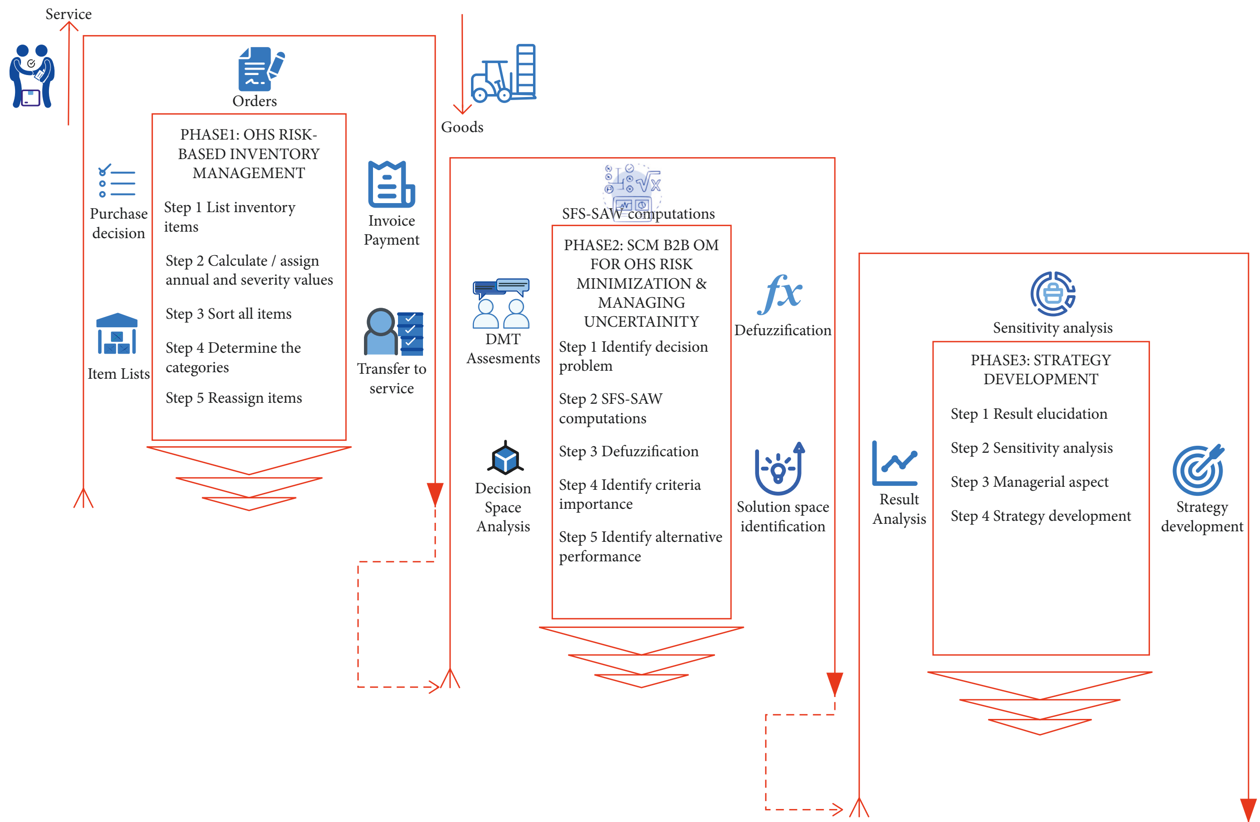

FIGURE 2: The proposed approach to minimize OHS risks.

$\widetilde{w}_k$: the normalized spherical fuzzy weighted importance of criteria k

$\widetilde{a}_{kj}$: the linguistic performance value of supplier j on criteria k

T_{tf}: the scenario t pertain to calculation run f.

3.2.3. Decision Variables

x_{ij}: if the inventory item i purchased from supplier j is equal to 1, otherwise 0

w_k: the overall defuzzified importance of criteria k

a_j: the defuzzified performance score of supplier j.

3.3. ABC Analysis. The ABC inventory control method was developed by the General Electric Company in the 1950s to help inventory management by categorization of the products, components, or raw materials to be purchased.

The following steps are followed in ABC analysis implementation to categorize goods for inventory control problems [17].

Step 1. All inventory items should be listed.

Step 2. The expected demand of all listed inventory items should be determined in units and the unit price by the employment of Equation (1).

$$\text{Annual investment value}_i = \frac{\text{Unit price}_{ij}}{\text{Cost}_{ij}} * \text{Annual demand}_i. \tag{1}$$

Step 3. All inventory items should be sorted by total annual investment values from the highest to the lowest one.

Step 4. The percentages of units for each item to the total units of all items and the total value of each item to the total value of all items should be calculated.

Step 5. The cumulative sums of the percentages found in Step 4 should be calculated.

Step 6. All inventoried items should be categorized according to the cumulative percentages found in Step 5.

The roots of the ABC analysis method go back to "Pareto's rule" of "Vital few and trivial many" based on the capital investment of the item which was proposed to related literature in 1896 by Italian economist Vilfredo Pareto [17]. This method provides a simple check for close control to separate entity types that do not require control from the essential ones by dividing inventoried goods into three separate groups: (i) *Category A* goods make up only 10% of the total quantity, while having 70% in sales value; (ii) *Category B* goods in the middle are 20% of the total amount with 20% and 15–20% share in sales value, and at the other extreme; (iii) *Category C* goods have only as little as 5% to 10% of sales value as 60% to 70% when producing total quantity [29]. Here, *Category A* needs the tightest control, *Category C* requires minimal attention, and *Category B* deserves less attention than *Category A* but more than *Category C*.

3.4. VED Analysis. VED (vital essential desirable) analysis is a technique for classifying inventories according to their functional importance or health-related supremacy.

VED analysis classifies the inventory items into three categories as vital (*V*), required (*E*), and desirable (*D*). Here, *Category V* includes critical goods for the health of employees and minimization of OHS risks, *Category E* represents inventory materials with lower critical importance than *Category V*, where inventory materials with the lowest severity to cause any OHS risks should be listed under *Category D* [18].

There is no denying that stocking particular items can be expensive and tie up a lot of capital and that bringing efficiencies to such important cost drivers—often 30–40% of the budget—can present meaningful savings [16]. On the other hand, the limitation of ABC analysis is that it is based only on monetary values and the cost of consumption of items; however, some items of low monetary value would be lifesaving or vital for human health. The importance of items belonging to this group should not be overlooked simply because they were not listed in *Category A* with the ABC method. On that occasion, an additional parameter of assessment according to the criticality levels of inventoried items for human health could be performed by VED analysis [21].

3.5. Spherical Fuzzy Sets. The concept of SFS was proposed by Kutlu Gündoğdu and Kahraman [48] and introduced to the related literature as an extension of intuitionistic fuzzy sets by synthesizing Pythagorean and Neutrosophic fuzzy sets. The SFS calculation mechanism grounds on the assumption that the sum of the squares of the fuzzy number element belonging to a fuzzy set, nonmembership, and hesitancy degrees will be less than or equal to 1, and here membership functions of fuzzy elements can be defined independently of each other, provided that they remain within the boundaries of a sphere [48–51].

According to the SFS, where E_1 and E_2 were assumed to be two universes and $\tilde{A}_s$ and $\tilde{B}_s$ were assumed to be the universe of discourse E_1 and E_2, the following mathematical equations could be employed (equations (2)–(7)).

$$\tilde{A}_s = \left\{u, \left(\mu_{\tilde{A}_s}(u), \nu_{\tilde{A}_s}(u), \pi_{\tilde{A}_s}(u)\right) \mid u \in E_1\right\}, \tag{2}$$

$$\tilde{B}_s = \left\{r, \left(\mu_{\tilde{B}_s}(r), \nu_{\tilde{B}_s}(r), \pi_{\tilde{B}_s}(r)\right) \mid r \in E_2\right\}, \tag{3}$$

$$\mu_{\tilde{A}_s}(u)\colon E_1 \longrightarrow [0,1], \nu_{\tilde{A}_s}(u)\colon E_1 \longrightarrow [0,1], \pi_{\tilde{A}_s}(u)\colon E_1 \longrightarrow [0,1], \tag{4}$$

$$\mu_{\tilde{B}_s}(r)\colon E_2 \longrightarrow [0,1], \nu_{\tilde{B}_s}(r)\colon E_2 \longrightarrow [0,1], \pi_{\tilde{B}_s}(r)\colon E_2 \longrightarrow [0,1], \tag{5}$$

$$0 \le \mu^2\tilde{A}_s(u) + \nu^2\tilde{A}_s(u) + \pi^2\tilde{A}_s(u) \le 1, \ \forall u \in E_1, \tag{6}$$

$$0 \le \mu^2\tilde{B}_s(r) + \nu^2\tilde{B}_s(r) + \pi^2\tilde{B}_s(r) \le 1, \ \forall r \in E_2. \tag{7}$$

Here, for each x and y, the membership function, the nonmembership function, and the hesitancy degree of element x and element y were represented $\mu\tilde{A}_s(u)$, $\nu\tilde{A}_s(u)$, and $\pi\tilde{A}_s(u)$, and $\mu\tilde{B}_s(r)$, $\nu\tilde{B}_s(r)$, and $\pi\tilde{B}_s(r)$, respectively [52].

The summation and multiplication of spherical fuzzy numbers and multiplication by scalar arithmetical operations were developed by Kutlu Gündoğdu and Kahraman [48], and are seen as follows:

$$\tilde{A}_s \oplus \tilde{B}_s = \left\{\left(\mu^2_{\tilde{B}_s} + \mu^2_{\tilde{B}_s} - \mu^2_{\tilde{A}_s}\mu^2_{\tilde{B}_s}\right)^{1/2}, \nu_{\tilde{A}_s}\nu_{\tilde{B}_s}, \left(\left(1-\mu^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1-\mu^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2}\right\}, \tag{8}$$

$$\tilde{A} \otimes \tilde{B}_s = \left\{\mu_{\tilde{A}_s}\mu_{\tilde{B}_s}, \left(\nu^2_{\tilde{A}_s} + \nu^2_{\tilde{B}_s} - \nu^2_{\tilde{A}_s}\nu^2_{\tilde{B}_s}\right)^{1/2}, \left(\left(1-\nu^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1-\nu^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2}\right\}, \tag{9}$$

$$k * \tilde{A}_s = \left\{\left(1-\left(1-\mu^2_{\tilde{A}_s}\right)^k\right)^{1/2}, \nu^k_{\tilde{A}_s}, \left(\left(1-\mu^2_{\tilde{A}_s}\right)^k - \left(1-\mu^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_s}\right)^k\right)^{1/2}\right\}. \tag{10}$$

Kutlu Gündoğdu and Kahraman [48] also developed SFS operators for spherical weighted arithmetical mean (SWAM) and spherical weighted geometric mean (SWGM) operations to be used in group decision-making processes with the below seen mathematical equations (equations (11)-(12)).

$$\text{SWAM}_w\left(\widetilde{A_{s1}},\ldots.,\widetilde{A_{sn}}\right)=w_1\widetilde{A_{s1}}+w_2\widetilde{A_{s2}}+\ldots..+wn\widetilde{A_{sn}}$$
$$=\left\{\begin{array}{l}\left[1-\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\boldsymbol{\mu}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}\right]^{1/2},\\ \prod_{\mathbf{k}=1}^{\mathbf{n}}\mathbf{v}^{\mathbf{w_k}}_{\widetilde{A_{sk}}},\left[\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\boldsymbol{\mu}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}-\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\boldsymbol{\mu}^2_{\widetilde{A_{sk}}}-\boldsymbol{\pi}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}\right]^{1/2},\end{array}\right. \tag{11}$$

$$\text{SWGM}w\left(\widetilde{A_{s1}},\ldots.,\widetilde{A_{sn}}\right)=w1\widetilde{A_{s1}}+w2\widetilde{A_{s2}}+\ldots..+wn\widetilde{A_{sn}}$$
$$=\left\{\prod_{\mathbf{k}=1}^{\mathbf{n}}\boldsymbol{\mu}^{\mathbf{w_k}}_{\widetilde{A_{sk}}},\left[1-\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\mathbf{v}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}\right]^{1/2},\left[\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\mathbf{v}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}-\prod_{\mathbf{k}=1}^{\mathbf{n}}\left(1-\mathbf{v}^2_{\widetilde{A_{sk}}}-\boldsymbol{\pi}^2_{\widetilde{A_{sk}}}\right)^{\mathbf{w_k}}\right]^{1/2}\right.. \tag{12}$$

Here, $w=(w_1,w_2,\ldots,w_n)$; w_k, $\in[0,1]$; $\sum_{k=1}^{n}w_k=1$.

Although it could be considered as a relatively newly developed fuzzy set concept, SFS has quickly gained a place in the related literature and has been used with various MCDM techniques. As instances of some valuable papers employed SFS, interested readers can benefit from the studies of Ashraf and Abdullah [49], Ashraf et al. [50], Kutlu Gündoğdu and Kahraman [48], Kutlu Gündoğdu and Kahraman [51], Kutlu Gündoğdu and Kahraman [53], Mathew et al. [52], Kutlu Gündogdu and Kahraman [54], Özceylan et al. [55], and Sharaf [56] (Table 2)

3.6. Proposed Approach

Stage 1. Inventory control operations aiming OHS risk minimization

Step 1.1. All inventory items should be listed.
Step 1.2. Annual inventory values and severity values should be calculated and assigned regarding each inventory item separately, by the employment of equation (1) and experience knowledge of DMs, respectively.
Step 1.3. All inventory items should be sorted from highest to the lowest regarding both listed values, respectively.
Step 1.4. Categories of *A*, *B*, and *C* and categories of *V*, *E*, and *D* should be determined according to the results of Step 1.3.
Step 1.5. All inventory items should be reassigned into three categories such as Category I, Category II, and Category III, according to the results of Step 1.4, and the assignment rules proposed by Gupta et al.[6]. Here, as Category I, all vital (V) inventory materials and all high-investment (*A*) inventory materials should be represented to be able to handle the components and products with the highest severity levels and investment volumes, including the subclasses of AV, BV, CV, AE, and AD. Second, among the remaining inventory materials, all items listed as essential (*E*) and midinvestment (*B*) should be grouped under Category II, including the subclasses of BE, BD, and CE, where all desirable (*D*) and low-investment (C) items should be grouped under Category III, including CD subclass. The categorization employed in integrated ABC-VED analysis implementations was presented hereinafter, in Table 2.

Stage 2. SFS-SAW implementation

Step 2.1. The decision problem and elements influencing the decision environment should be defined.
Step 2.2. Evaluation matrices should be constituted for SFS-SAW computations with the use of linguistic terms.
Step 2.3. Linguistic terms in SFS-SAW evaluation matrices should be transformed into spherical numbers with the employment of identified linguistic assessment scale.
Step 2.4. Aggregated SFS-SAW evaluation matrices ($\tilde{a}$ kj: $(C_j(\widetilde{a_k})_{mxn})$) should be constructed with the employment of equation (11) or equation (12) on the SFS-SAW matrices of Step 2.3.
Step 2.5. Different DM assessments should be aggregated with the SWGM operator introduced in equation (12), in the case of group decision-making processes.
Step 2.6. Spherical fuzzy criteria scores $S(\widetilde{w}_k)$) and normalized spherical fuzzy criteria weighting values ($\widetilde{w}_k$) should be computed with the employment of equations (13)-(14), respectively.

$$S(\widetilde{w}_k)=\left(\frac{3\mu_k-\pi_k}{2}\right)^2-\left(\frac{\nu_k-\pi_k}{2}\right)^2, \tag{13}$$

$$\widetilde{w}_k=\frac{S(\widetilde{w}_k)}{\sum_{k=1}^{n}S(\widetilde{w}_k)}. \tag{14}$$

Step 2.7. Spherical fuzzy values of alternative overall performances on the determined criteria set should be computed by the employment of the results of Step 2.6 and aggregated decision matrix, as introduced in equation (15).

$$\widetilde{A}k=\sum_{j=1}^{n}\widetilde{w}_j\widetilde{a}_{kj}\forall k. \tag{15}$$

Step 2.8. Final scores of alternatives (a_j) should be computed as introduced in equation (16), and, the alternative with the highest a_j score should be

Table 2: Categorization in integrated ABC-VED analysis.

Categories	V	E	D
A	AV	AE	AD
B	BV	BE	BD
C	CV	CE	CD

Table 3: DMs profiles.

Expertise field	Gender	Age	Title	Background	Experience
Purchasing and B2B relations	Male	45	Purchasing manager	Business Administration (B.Sc.)	25
OHS	Female	37	Job safety expert	Industrial Engineering (M.Sc.)	12
Purchasing and B2B relations	Male	42	Purchasing expert	Business Administration (B.Sc.)	21

identified as the one having the best performance on the determined criteria set.

$$Aj = \text{Score}\left(\widetilde{A_j}\right) = \left(\frac{3\mu_{\tilde{A}_i} - \pi_{\tilde{A}_i}}{2}\right)^2 - \left(\frac{\nu_{\tilde{A}_i} - \pi_{\tilde{A}_i}}{2}\right)^2. \quad (16)$$

Stage 3. Further analysis and elicitation of results.

Step 3.1. The obtained results and modifications regarding criteria importance levels according to identified item groups and preference levels related to alternatives according to the OHS risk minimization objective should be furtherly analyzed.

Step 3.2. Sensitivity analysis should be performed in terms of developed scenarios reflecting varying dominion relations of diverse problem space perspectives.

Step 3.3. Strategies for differing planning periods should be developed and managerial insights and practical implications related to these should be delineated.

4. Results and Discussion

The oldest and the second largest gas distribution company in Turkey was analyzed as the case study, which serves more than 2 million subscribers in the Capital, Ankara, with a population of 5 million. This energy company has a license valid until 2037, it serves approximately 7% of the total population of Turkey in only the Capital.

The company carries out its B2B relations in cooperation with suppliers based on trust, to ensure that they perform quality production and services to their customers, while, complying with rigidly restricted OHS rules. Out of 270 different items to be purchased and 197 to be inventoried, 103 items were determined as potentially causing OHS risks for employees and having potential adverse impact on customers' health.

The group decision making method was employed in this research; a decision making team consisting of three DMs who have proven their expertise in their fields was constituted to participate in assessments. Information and demographics of DMs who took part in decision problem solution are presented to the reader (see Table 3). In this application, all DMs were accepted as having same influence on B2B decisions, which also means that there is no superiority of any DMs to another one.

4.1. Integrated ABC-VED Analysis Results. The developed integrated ABC-VED inventory control method was implemented as it was proposed by Gupta et al. [17]. The results of both ABC analysis and VED analysis, furthermore, the categorization of all 103 inventoried items having influence on OHS risks and employee/customer health verdict to integrated ABC-VED analysis are combined presented (see Table 4). The overall results are summarized for the convenience of readers in Table 5.

As it is indicated in Tables 4 and 5, not all 103 items out of 197 inventoried products and components were categorized as having the highest priority in terms of OHS risks, besides they were preliminarily listed as essential to human health. The distribution of integrated overall categories (Category I, Category II, and Category III), ABC categories, and VED categories are presented. Figure 3 is presented to scrutinize the distribution and assignment of inventoried essential items regarding the Stage 1 results.

According to the results, items assigned in Category I, which must be considered carefully in the highest criticality level, correspond to 50.48% of the total materials and 61% of the total material value. Items listed in the Category II correspond to 43.69% of the total materials and 27% of the total value. Hence, it is proved by the results that items in Category II areless important than those listed in Category I in terms of both amount and value.

The least important items categorized in Category III correspond to 0.06% of the total materials and 12% of the total value. According to Stage 1 results regarding inventory control problem aiming minimization of OHS risks, 51 out of 103 items were identified as the most critical items with the employment of integrated ABC-VED analysis.

4.2. Integrated SFS-SAW Analysis Results and Discussion. As Stage 2, analysis for B2B relationship management to minimize OHS risks was performed grounding on the results of integrated ABC-VED results by the employment of the SFS-SAW MCDM method regarding the supplier companies of relating varying products and components. 51 items assigned into categories according to their influence on OHS risks (represented with VED results) and overall market

Table 4: Stage 1 calculations.

Items	Percentage values	Cumulative values	ABC categories	VED categories	Overall categories
Rotary. G40 Dn50 150 1/160 Pmax 19,3	0.16906	0.16906	*A*	*E*	Category I
Diaphragm meter G25 Dn50	0.13199	0.30106	*A*	*E*	Category I
Diaphragm meter G10 Dn40	0.10337	0.40443	*A*	*E*	Category I
Rotary. G400 Dn150 1501/160 Pmax19,3	0.09343	0.49786	*A*	*V*	Category I
Diaphragm meter G16 Dn40	0.09154	0.58940	*A*	*V*	Category I
Rotary. G100 Dn80 150 1/160 Pmax 19,3	0.07123	0.66063	*A*	*E*	Category I
Rotary. G650 Dn150 150 1/200 P19,3 Hf	0.04747	0.70810	*B*	*V*	Category I
Rotary. G65 Dn50 150 1/160 Pmax 19, 3	0.04263	0.75072	*B*	*E*	Category II
Rotary. G250 Dn100 150 1/160 Pmax19, 3	0.02990	0.78063	*B*	*V*	Category I
Saddle 3-way sphere type 12″ × 12″	0.02540	0.80602	*B*	*D*	Category II
Saddle 3-way sphere type 8″ × 8″	0.02028	0.82630	*B*	*D*	Category II
Rotary. G160 Dn80 150 1/160 Pmax 19, 3	0.01764	0.84394	*B*	*E*	Category II
Saddle 3-way saddle type 8″ × 4″	0.01127	0.85521	*B*	*E*	Category II
Saddle 3-way collar type 12″ × 4″	0.01094	0.86615	*B*	*V*	Category I
Dıaphragm meter G6 Dn25	0.00959	0.87575	*B*	*E*	Category II
Regulator 75 m3/H 2–4 Bar/21 mbar	0.00858	0.88432	*B*	*V*	Category I
Saddle 3-way saddle type 8″ × 6″	0.00840	0.89273	*B*	*E*	Category II
Saddle 3-way saddle type 6″ × 6″	0.00796	0.90069	*C*	*E*	Category II
Saddle 3-way sphere type 6″ × 6″	0.00794	0.90863	*C*	*D*	Category III
Regulator 100 m3/H 2–4 Bar/300 mbar	0.00707	0.91570	*C*	*V*	Category I
Saddle 3-way *N* type 12″ × 2″	0.00683	0.92253	*C*	*E*	Category II
Saddle 3-way sphere type 6″ × 4″	0.00636	0.92889	*C*	*D*	Category III
Saddle 3-way collar type 16″ × 4″	0.00629	0.93519	*C*	*V*	Category I
Saddle 3-way saddle type 4″ × 4″	0.00595	0.94114	*C*	*E*	Category II
Saddle 3-way *N* type 8″ × 2″	0.00592	0.94706	*C*	*E*	Category II
Saddle 3-way saddle type 12″ × 8″	0.00580	0.95287	*C*	*E*	Category II
Saddle 3-way *N* type 6″ × 2″	0.00449	0.95735	*C*	*E*	Category II
Saddle 3-way *N* type 16″ × 2″	0.00384	0.96119	*C*	*E*	Category II
Blind flange 3″ Pn16	0.00349	0.96468	*C*	*E*	Category II
Saddle 3-way sphere type 8″ × 4″	0.00343	0.96811	*C*	*D*	Category III
Regulator 50 m3/H 2–4 Bar/300 mbar	0.00287	0.97098	*C*	*V*	Category I
Elbow ST 45° 12″ WPB 9.53 mm	0.00278	0.97376	*C*	*E*	Category II
Elbow ST 90° 12″ WPB 9.53 Mm	0.00213	0.97589	*C*	*V*	Category I
Bellow ST Gear 2″	0.00152	0.97741	*C*	*E*	Category II
Elbow ST 45° 6″ WPB 7.11 Mm	0.00126	0.97867	*C*	*E*	Category II
Elbow ST 22.50° 12″ WPB 9.53 Mm	0.00121	0.97988	*C*	*V*	Category I
Regulator 25 m3/H 2–4 Bar/21 mbar 180°	0.00115	0.98103	*C*	*V*	Category I
Flange neck 4″ Ansı300	0.00111	0.98214	*C*	*V*	Category I
Regulator100 m3/H 2–4 Bar/21 mbar	0.00105	0.98320	*C*	*V*	Category I
KEP ST 12″ WPB 9.53 Mm	0.00092	0.98412	*C*	*V*	Category I
Elbow ST 90° 16″ WPB 9.53 Mm	0.00091	0.98503	*C*	*E*	Category II
Motherboard	0.00089	0.98592	*C*	*E*	Category II
KEP ST 24″ WPHY52 9.53 Mm	0.00082	0.98674	*C*	*V*	Category I
Elbow ST 22.50° 16″ WPB 9.53 Mm	0.00079	0.98753	*C*	*V*	Category I
Blind flange 6″ Pn16	0.00073	0.98826	*C*	*E*	Category II
Metallic flexible block-rear cabinet combined kit	0.00072	0.98898	*C*	*E*	Category II
TEE Inegal 12″ × 4″ WPB 9.53 × 6.02 Mm	0.00071	0.98970	*C*	*V*	Category I
KEP ST 16″ WPB 9.53 mm	0.00063	0.99033	*C*	*V*	Category I
TEE Inegal 12″ × 8″ Wpb 9.53 × 8.18 Mm	0.00063	0.99096	*C*	*V*	Category I
Regulator 75 m3/H 2–4 Bar/21 mbar 180°	0.00057	0.99153	*C*	*V*	Category I
Weldolet 8′—2′ 3000 lb	0.00045	0.99198	*C*	*V*	Category II
Gas Suction Pump	0.00039	0.99237	*C*	*E*	Category II
Reduction ST 16″ × 12″ WPB 9.53 × 9.53 Mm	0.00038	0.99275	*C*	*V*	Category I
CO Sensor	0.00037	0.99312	*C*	*E*	Category II
Lel/Gas Sensor	0.00036	0.99349	*C*	*E*	Category II
TEE Inegal 12″ × 6″ WPB 9.53 × 7.11 Mm	0.00036	0.99384	*C*	*V*	Category I
Elbow ST 11.25 12″ WPB 9.53 Mm	0.00034	0.99418	*C*	*V*	Category I
Blind Flange 10″ Class600	0.00032	0.99450	*C*	*E*	Category II
TEE Inegal 6″ × 4″ WPB 7.11 × 6.02 Mm	0.00031	0.99481	*C*	*V*	Category I

Table 4: Continued.

Items	Percentage values	Cumulative values	ABC categories	VED categories	Overall categories
Weldolet 12′—2′ 3000 lb	0.00031	0.99513	C	V	Category I
Flange Neck 16″ Pn16	0.00027	0.99540	C	V	Category I
Motherboard Psu Unıt	0.00026	0.99566	C	E	Category II
TEE Inegal 8″ × 4″ WPB 8.18 × 6.02 Mm	0.00025	0.99591	C	V	Category I
Flange Neck 6″ Pn16	0.00022	0.99613	C	V	Category I
LCD Screen	0.00022	0.99635	C	E	Category II
Regulator 50 m3/H 2–4 Bar/21 mbar 180°	0.00022	0.99657	C	V	Category I
KEP ST 8″ WPB 8.18 Mm	0.00021	0.99678	C	V	Category I
Stainless steel open-end 35 cm Probe for high Temperature gas controls	0.00019	0.99697	C	E	Category II
Blind Flange 12″ Pn16	0.00018	0.99715	C	E	Category II
KEP ST 6″ WPB 7.11 Mm	0.00017	0.99731	C	V	Category I
Blind flange 423 Cls300	0.00016	0.99748	C	E	Category II
Closed ended side hole 35 cm plastic probe for ground gas leak detection	0.00015	0.99763	C	E	Category II
Blind flange 6″ Cls150	0.00015	0.99777	C	E	Category II
Front cabin block	0.00014	0.99792	C	E	Category II
Weldolet 24’—2’ 3000lb	0.00014	0.99805	C	V	Category I
TEE equal 6″ WPB 7.11 Mm	0.00013	0.99819	C	V	Category I
KEP ST 4″ WPB 6.02 Mm	0.00013	0.99832	C	V	Category I
Weldolet 18′—2′ 3000 lb	0.00012	0.99844	C	V	Category I
Carbon filter material 1 kg	0.00012	0.99856	C	E	Category II
PPM sensor	0.00011	0.99867	C	E	Category II
Reduction 12″ × 8″ WPB 12.7 × 12.7 Mm	0.00009	0.99876	C	V	Category I
Blind Flange 2″ Ansı300	0.00009	0.99885	C	E	Category II
ELBOW ST 45° 4″ WPB 6.02 Mm	0.00009	0.99893	C	E	Category II
Blind Flange 8″ Pn16	0.00008	0.99902	C	E	Category II
ELBOWST 90° 6″ WPB 7.11 Mm	0.00008	0.99909	C	V	Category I
Calibratıon	0.00008	0.99917	C	E	Category II
Weldolet 16′—2′ 3000 lb	0.00007	0.99925	C	V	Category I
Blind Flange 2″ Ansı 150	0.00007	0.99932	C	E	Category II
Maintenance-repair cost	0.00007	0.99938	C	D	Category III
Silica filter/carbon filter block	0.00006	0.99944	C	E	Category II
Battery block cover	0.00006	0.99951	C	E	Category II
Weldolet 6′—½′ 3000 lb	0.00006	0.99957	C	V	Category I
Weldolet 12′—½′ 3000 lb	0.00006	0.99963	C	V	Category I
Flange neck 2″ 300	0.00006	0.99969	C	V	Category I
Weldolet 8′—½′ 3000 lb	0.00006	0.99975	C	V	Category I
Protection Sheath	0.00006	0.99980	C	D	Category III
Weldolet 4′—½′ 3000 lb	0.00005	0.99985	C	V	Category I
Silica gel filter material 1 kg	0.00004	0.99990	C	E	Category II
Flange flat open 8″ Cls150	0.00003	0.99992	C	V	Category I
Weldolet 6′—2′ 3000 lb	0.00003	0.99995	C	V	Category I
Powder Pack 30	0.00002	0.99997	C	D	Category III
Hydrophobic filter-1 piece	0.00002	0.99999	C	E	Category II
Flange slip-on 4″ Ansı150	0.00001	1.00000	C	V	Category I

structure (represented with ABC results) were analyzed under six headings, since the supplier companies of the items could be grouped for item subsets (see Table 5). Item groups obtained in terms of the supplier companies and related investment values for each item group are presented in Table 6, where the list of all inventoried items according to the related item groups is also presented to the readers in Table7.

Since having the responsibility to present continuous service with high quality standards as being the leader energy company in gas distribution market obstructs the existing challenges in OHS risk minimization and B2B relations, the company asserts several prerequisites to their possible suppliers, which narrows down the alternatives set. There are two possible supplier companies regarding the purchase of the items listed under the Calibration and Maintenance group (SU, ESA), where three and four supplier companies could be able to be considered for items under Saddles, and Regulators and Components groups (PR, TD, GIO; ES, GA, FI), and meter I and meter II groups (NA, KA, MA, EL; NA, ME, MA, EL), respectively. The number of certified suppliers for items grouped under Steel Fittings is again three possible

Table 5: Integrated ABC-VED results.

Categories	Count	Cost (TL)	%	
			Cost	Count
I (AV + AE + AD + BV + CV)	51	4673565.36	0.61	0.50
II (BE + CE + BD)	46	2077409.89	0.27	0.44
III (CD)	6	933500.96	0.12	0.06
Total	103	7684476.21	1.00	1.00

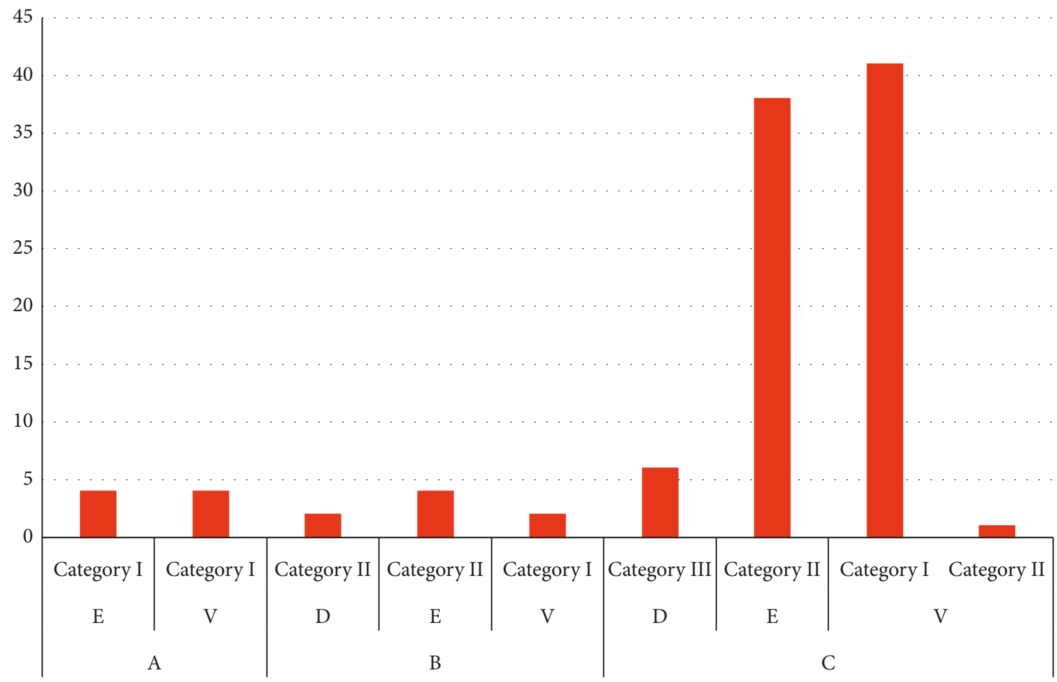

Figure 3: Distribution of inventoried item into categories.

Table 6: Category I item groups according to supplier companies.

Item groups	Costs (TL)
Calibration and maintenance	33315
Meter I	2585782
Meter II	3622200
Saddles	1084407
Regulators and components	165302
Steel fittings	193469
Total	7684476

supplier companies (SAY, MAN, MET). Company names of the suppliers are given in abbreviations due to secrecy policies of the organization. Since the alternative supplier companies vary according to the identified item groups, Stage 2 substeps of the proposed approach was implemented in six rounds for each item group separately, from Step 2.1 to Step 2.8, respectively. The SWGM operator introduced in (12) was employed to create aggregated SFS-SAW evaluation matrices.

The criteria set was created in the light of the performed delineated literature review [57–68] and the field knowledge of DMs. Dickson [69] conducted one of the first and most comprehensive studies on supplier selection problem through a questionnaire research applied to 273 randomly selected purchasing experts and executives from the National Association of Purchasing, USA. 23 criteria were identified in results, with the most important ones being product quality, on-time delivery, and warranty policy [69]. Price, Lead time, Damaged/delinquent delivery, Reliability, Warranty terms, and Trade volume criteria were determined to be considered as the decision criteria for the handled B2B relationship management problem according to the employment frequency of each criterion in the related literature and the insights and opinions of DMs according to their field experience. 1–9 Likert type linguistic term scale was employed to reflect DMs' judgements into the results at best (see Table 8). The evaluation matrices regarding alternative organization performances on the identified criteria set are presented in Table 9 for each DM and item group separately, where the $S(\widetilde{w}_j)$, $\overline{w}_j$, and final criteria weight values, and $\widetilde{A}_{ji}$, a_{ji}, and final alternative scores are presented in Tables 10 and 11, respectively, for each item group.

As Tables 10 and 11 indicated both criteria weights and performances of even same companies on the identified criteria set were varying according to corresponding item groups. The ESA, KA, EL, TD, and ES supplier companies were selected to perform best related to B2B relationship achievement levels in terms of OHS risk minimization target grounding on the criteria set includes six identified criteria "Cost," "Lead time," "Damaged/delinquent delivery,"

Table 7: Category I items under identified item groups.

Item groups	Inventoried items
Calibration and maintenance	BATTERY BLOCK COVER
Steel fittings	BELLOW ST GEAR 2″
Steel fittings	BLIND FLANGE 3″ PN16
Steel fittings	BLIND FLANGE 4″ CLS300
Steel fittings	BLIND FLANGE 10″ CLASS600
Steel fittings	BLIND FLANGE 12″ PN16
Steel fittings	BLIND FLANGE 2″ ANSI 150
Steel fittings	BLIND FLANGE 2″ ANSI300
Steel fittings	BLIND FLANGE 6″ Cls150
Steel fittings	BLIND FLANGE 6″ PN16
Steel fittings	BLIND FLANGE 8″ PN16
Calibration and maintenance	CALIBRATION
Calibration and maintenance	CARBON FILTER MATERIAL 1 kg
Calibration and maintenance	CLOSED ENDED SIDE HOLE 35 cm PLASTIC PROBE FOR GROUND GAS LEAK DETECTION
Calibration and maintenance	CO SENSOR
Meter I	DIAPHRAGM METER G10 DN40
Meter I	DIAPHRAGM METER G16 DN40
Meter I	DIAPHRAGM METER G25 DN50
Meter I	DIAPHRAGM METER G6 DN25
Steel fittings	ELBOW ST 11.25°12″ WPB 9.53 mm
Steel fittings	ELBOW ST 22.50° 12″ WPB 9.53 mm
Steel fittings	ELBOW ST 22.50° 16″ WPB 9.53 mm
Steel fittings	ELBOW ST 45° 12″ WPB 9.53 mm
Steel fittings	ELBOW ST 45° 4″ WPB 6.02 mm
Steel fittings	ELBOW ST 45° 6″ WPB 7.11 mm
Steel fittings	ELBOW ST 90° 16″ WPB 9.53 mm
Steel fittings	ELBOWST 90° 12″ WPB 9.53 mm
Steel fittings	ELBOWST 90° 6″ WPB 7.11 mm
Steel fittings	FLANGE FLAT OPEN 8″ CLS150
Steel fittings	FLANGE Neck 2″ ANSI300
Steel fittings	FLANGE Neck 4″ ANSI300
Steel fittings	Flange neck 16″ PN16
Steel fittings	Flange neck 6″ PN16
Steel fittings	Flange slip-ON 4″ ANSI150
Calibration and maintenance	Front cabin block
Calibration and maintenance	Gas suction pump
Calibration and maintenance	Hydrophobic filter-1 piece
Steel fittings	KEP ST 12″ WPB 9.53 mm
Steel fittings	KEP ST 16″ WPB 9.53 mm
Steel fittings	KEP ST 24″ WPHY52 9.53 mm
Steel fittings	KEP ST 4″ WPB 6.02 mm
Steel fittings	KEP ST 6″ WPB 7.11 mm
Steel fittings	KEP ST 8″ WPB 8.18 mm
Calibration and maintenance	LCD screen
Calibration and maintenance	LEL/gas sensor
Calibration and maintenance	Maintenance-repair cost
Calibration and maintenance	Metallic flexible block and rear cabinet combined kit
Calibration and maintenance	Motherboard
Calibration and maintenance	Motherboard PSU unit
Calibration and maintenance	Powder pack 30
Calibration and maintenance	PPM sensor
Calibration and maintenance	Protection sheath
Steel fittings	Reduction 12″ × 8″ WPB 12.7 × 12.7 mm
Steel fittings	Reduction ST 16″ × 12″ WPB 9.53 × 9.53 mm
Regulators and components	Regulator 100 m3/h 2–4 bar/300 mbar
Regulators and components	REGULATOR 25 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR 50 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR 75 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR100 m3/h 2–4 bar/21 mbar

Table 7: Continued.

Item groups	Inventoried items
Regulators and components	REGULATOR50 m3/h 2–4 bar/300 mbar
Regulators and components	REGULATOR75 m3/h 2–4 bar/21 mbar
Meter II	Rotary. G40 DN50ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G100 DN80ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G160 DN80ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G250 DN100ANSI150 1/160 Pmax19, 3
Meter II	Rotary. G400 DN150ANSI1501/160 Pmax19, 3
Meter II	Rotary. G65 DN50ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G650 DN150ANSI150 1/200 P19, 3 HF
Saddles	SADDLE 3-WAY COLLAR TYPE 12″ × 4″
Saddles	SADDLE 3-WAY COLLAR TYPE 16″ × 4″
Saddles	SADDLE 3-WAY N TYPE 12″ × 2″
Saddles	SADDLE 3-WAY N TYPE 16″ × 2″
Saddles	SADDLE 3-WAY N TYPE 6″ × 2″
Saddles	SADDLE 3-WAY N TYPE 8″ × 2″
Saddles	SADDLE 3-WAY SADDLE TYPE 4″ × 4″
Saddles	SADDLE 3-WAY SADDLE TYPE 6″ × 6″
Saddles	SADDLE 3-WAY SADDLE TYPE 8″ × 4″
Saddles	SADDLE 3-WAY SADDLE TYPE 8″ × 6″
Saddles	SADDLE 3-WAY SADDLE TYPEP 12″ × 8″
Saddles	SADDLE 3-WAY SPHERE TYPE 12″ × 12″
Saddles	SADDLE 3-WAY SPHERE TYPE 8″ × 4″
Saddles	SADDLE 3-WAY SPHERE TYPE 8″ × 8″
Saddles	SADDLE 3-WAY SPHERE TYPE 6″ × 4″
Saddles	SADDLE 3-WAY SPHERE TYPE 6″ × 6″
Calibration and maintenance	SILICA FILTER/CARBON FILTER BLOCK
Calibration and maintenance	SILICA GEL FILTER MATERIAL 1 kg
Calibration and maintenance	STAINLESS STEEL OPEN-END 35 cm PROBE FOR HIGH TEMPERATURE GAS CONTROLS
Steel fittings	TEE EQUAL 6″ WPB 7.11 mm
Steel fittings	TEE INEGAL 12″ × 6″ WPB 9.53 × 7.11 mm
Steel fittings	TEE INEGAL 12″ × 8″ WPB 9.53 × 8.18 MM
Steel fittings	TEE INEGAL 6″ × 4″ WPB 7.11 × 6.02 mm
Steel fittings	TEE INEGAL 8″ × 4″ WPB 8.18 × 6.02 mm
Steel fittings	TEE INEGAL 12″ × 4″ WPB 9.53 × 6.02 mm
Steel fittings	WELDOLET 12′—½′ 3000LB
Steel fittings	WELDOLET 12′—2′ 3000LB
Steel fittings	WELDOLET 16′—2′ 3000LB
Steel fittings	WELDOLET 18′—2′ 3000LB
Steel fittings	WELDOLET 24′—2′ 3000LB
Steel fittings	WELDOLET 4′—½′ 3000LB
Steel fittings	WELDOLET 6′—½′ 3000LB
Steel fittings	WELDOLET 6′—2′ 3000LB
Steel fittings	WELDOLET 8′—½′ 3000LB
Steel fittings	WELDOLET 8′—2′ 3000LB

Table 8: Linguistic terms and corresponding SFNs.

Linguistic terms	SFNs
Absolutely more important (AMI)	(0.9, 0.1, 0.1)
Very high important (VHI)	(0.8, 0.2, 0.2)
High important (HI)	(0.7, 0.3, 0.3)
Slightly more important (SMI)	(0.6, 0.4, 0.4)
Equally important (EI)	(0.5, 0.5, 0.5)
Slightly low important (SLI)	(0.4, 0.6, 0.4)
Low important (LI)	(0.3, 0.7, 0.3)
Very low important (VLI)	(0.2, 0.8, 0.2)
Absolutely low important (ALI)	(0.1, 0.9, 0.1)

"Reliability," "Warranty terms," and "Trade volume" regarding the first four item groups determined in terms of the supplier companies of the included inventoried items. The supplier ES was found to be the best in B2B relationship management regarding the fifth- and sixth-item groups.

Some additional examinations were made on the research results as further analysis of the outcomes. The modification of criteria weights according to item groups is visualized in Figure 4, where difference between the alternative supplier companies are investigated furtherly with Figure 5.

According to SFS-SAW computation outcomes grounding on integrated ABC-VED implementation results, "Damaged/delinquent delivery" criterion was found to have

Table 9: SFS-SAW evaluation matrices corresponding to supplier data and DM assessments.

DM1						
	Criteria					
	Calibration and maintenance					
Alternatives	COST	LEAD TIME	DDD	RELIABILITY	WARRANTY TERMS	TRADE VOLUME
SU	LI	LI	VHI	LI	HI	HI
ESA	EI	EI	HI	VHI	SMI	HI
Meter I						
NA	SMI	LI	SLI	VHI	VHI	HI
KA	EI	EI	LI	HI	HI	SMI
MA	EI	LI	EI	SMI	HI	EI
EL	SLI	SLI	SLI	VHI	VHI	EI
Meter II						
NA	SLI	SMI	EI	SMI	HI	SMI
KA	EI	SMI	HI	HI	SMI	SMI
MA	HI	SLI	SMI	SMI	HI	VHI
EL	SMI	SMI	SLI	HI	HI	HI
Saddles						
PR	HI	HI	SLI	SMI	HI	VHI
TD	SLI	AMI	HI	SMI	HI	AMI
GIO	AMI	SLI	SLI	VHI	VHI	HI
Regulator and parts						
ES	SMI	HI	SLI	HI	SMI	SMI
GA	SLI	HI	HI	SLI	SMI	HI
FI	VHI	EI	SMI	EI	SMI	SMI
Steel fittings						
SAY	HI	HI	SMI	HI	SMI	VHI
MAN	SMI	EI	HI	VHI	SMI	VHI
MET	SLI	HI	HI	VHI	SMI	SMI
DM2						
SU	LI	LI	SMI	VHI	SMI	VHI
ESA	HI	HI	SLI	SMI	LI	VHI
Meter I						
NA	HI	SMI	HI	SMI	SMI	HI
KA	EI	VHI	EI	HI	HI	HI
MA	EI	SLI	EI	VHI	HI	VHI
EL	SLI	SMI	SLI	HI	VHI	VHI
Meter II						
NA	LI	SMI	SMI	EI	HI	SMI
KA	SLI	SMI	HI	VHI	HI	EI
MA	HI	SLI	EI	SMI	SMI	HI
EL	EI	SMI	SLI	HI	HI	VHI
Saddles						
PR	VHI	EI	EI	SMI	HI	VHI
TD	EI	HI	SMI	EI	SMI	VHI
GIO	AMI	LI	LI	HI	VHI	EI
Regulator and parts						
ES	EI	SMI	EI	HI	HI	SMI
GA	LI	SMI	VHI	EI	SMI	HI
FI	HI	LI	SMI	SMI	EI	HI
Steel fittings						
SAY	VHI	SMI	HI	HI	EI	HI
MAN	SMI	LI	SMI	SMI	SMI	HI
MET	SLI	SMI	VHI	AMI	SMI	EI
DM3						
SU	LI	VLI	EI	HI	VHI	EI
ESA	VHI	HI	VHI	EI	EI	EI
Meter I						
NA	VHI	EI	SMI	SLI	HI	HI

Table 9: Continued.

			DM1			
			Criteria			
			Calibration and maintenance			
Alternatives	COST	LEAD TIME	DDD	RELIABILITY	WARRANTY TERMS	TRADE VOLUME
KA	SMI	HI	HI	EI	SMI	VHI
MA	EI	SLI	HI	HI	VHI	VHI
EL	SLI	EI	EI	HI	HI	LI
Meter II						
NA	SLI	SMI	EI	SMI	HI	HI
KA	EI	SMI	SMI	HI	HI	EI
MA	HI	LI	HI	SMI	SMI	HI
EL	SMI	SMI	SLI	VHI	HI	VHI
Saddles						
PR	SMI	SMI	LI	HI	HI	HI
TD	VLI	VHI	SMI	SMI	HI	VHI
GIO	VHI	VLI	LI	AMI	VHI	SMI
Regulator and parts						
ES	SLI	SMI	SMI	VHI	SMI	HI
GA	VLI	HI	VHI	SLI	EI	HI
FI	SMI	EI	HI	EI	EI	SMI
Steel fittings						
SAY	HI	EI	VHI	AMI	EI	HI
MAN	EI	VLI	HI	EI	EI	VHI
MET	LI	EI	SMI	VHI	EI	SMI
DMs						
DM1	VHI	VHI	VHI	HI	HI	EI
DM2	SMI	HI	VHI	VHI	HI	SLI
DM3	VHI	HI	HI	HI	SLI	LI
Meter I						
DM1	VHI	HI	SMI	EI	SMI	HI
DM2	VHI	HI	SMI	SMI	SMI	VHI
DM3	HI	HI	EI	EI	SMI	VHI
Meter II						
DM1	AMI	HI	HI	SMI	HI	SMI
DM2	VHI	HI	HI	SMI	VHI	HI
DM3	AMI	SMI	EI	HI	HI	VHI
Saddles						
DM1	HI	VHI	VHI	SMI	SMI	SMI
DM2	HI	HI	HI	HI	SMI	VHI
DM3	VHI	VHI	HI	VHI	SMI	HI
Regulator and parts						
DM1	SMI	EI	SMI	HI	HI	VHI
DM2	EI	SMI	SMI	VHI	HI	VHI
DM3	EI	SMI	SMI	HI	VHI	AMI
Steel fittings						
DM1	AMI	VHI	HI	HI	LI	SMI
DM2	VHI	HI	SMI	SMI	LI	SMI
DM3	AMI	AMI	SMI	SMI	EI	HI

the highest importance ($w_k = 0.231$) in B2B relationship management regarding OHS risks minimization for corresponding item group "Calibration and Maintenance." The most vital criteria corresponding to differing inventoried item groups were indicated as diversifying as well; "Cost" criterion was identified as the most important for item groups Meter II and Steel Fittings ($w_k = 0.272$; $w_k = 0.307$); similarly, "Trade volume" criterion was identified as the most important criteria for item groups Meter I and Regulator and Parts ($w_k = 0.240$; $w_k = 0.280$), respectively. Furthermore, "Lead time" ($w_k = 0.205$) criterion was determined as having the biggest impact in terms of the item group Saddles. As the results indicate, due to the complexity and vagueness included in the decision problem structure, while it was revealed that the results obtained vary in a wide range for each examined item group, the final weight scores of the criteria on the basis of groups are very close to each other in some cases (see Table 10 and Figure 4). This

Table 10: $S(\widetilde{w}_k)$, $\overline{w}_k$ and final criteria weight results corresponding varying item groups.

	Cost	Lead time	DDD	Reliability	Warranty terms	Trade volume
Calibration & maintenance						
$S(\widetilde{w}_k)$	4.116	4.222	4.719	4.222	2.387	0.780
$\overline{w}_k$	0.201	0.207	0.231	0.207	0.117	0.038
Meter I						
$S(\widetilde{w}_k)$	4.719	3.780	2.123	1.787	2.520	4.719
$\overline{w}_k$	0.239	0.192	0.108	0.091	0.128	0.240
Meter II						
$S(\widetilde{w}_k)$	6.370	3.302	2.783	2.885	4.222	3.687
$\overline{w}_k$	0.274	0.142	0.120	0.124	0.182	0.159
Saddles						
$S(\widetilde{w}_k)$	4.222	4.719	4.222	3.687	2.520	3.687
$\overline{w}_k$	0.183	0.205	0.183	0.160	0.109	0.160
Regulator and parts						
$S(\widetilde{w}_k)$	1.787	2.123	2.520	4.222	4.222	5.796
$\overline{w}_k$	0.086	0.103	0.122	0.204	0.204	0.280
Steel fittings						
$S(\widetilde{w}_k)$	6.370	5.175	2.885	2.885	0.565	2.885
$\overline{w}_k$	0.307	0.249	0.139	0.139	0.027	0.139
Criteria rank						
Calibration and maintenance	3	2	1	2	4	5
Meter I	2	3	5	6	4	1
Meter II	1	4	6	5	2	3
Saddles	2	1	2	3	5	4
Regulator & parts	5	4	3	2	2	1
Steel fittings	1	2	3	4	5	3

Table 11: $\widetilde{A}_j$, a_j, and final alternative score results corresponding varying item groups.

			Rank				
Calibration and maintenance				Saddles			
SU	(0.228, 0.894, 0.164)	−0.297	2	PR	(0.915, 0.178, 0.170)	7.068	2
ESA	(0.313, 0.860, 0.201)	0.125	1	TD	(0.915, 0.185, 0.166)	7.070	1
Meter I				GIO	(0.900, 0.219, 0.150)	6.86375	3
NA	(0.289, 0.849, 0.180)	0.029	4	Regulator and parts			
KA	(0.339, 0.854, 0.205)	0.270	1	ES	(0.956, 0.127, 0.131)	7.856	1
MA	(0.335, 0.865, 0.206)	0.233	2	GA	(0.948, 0.151, 0.125)	7.734	3
EL	(0.320, 0.880, 0.184)	0.135	3	FI	(0.952, 0.137, 0.144)	7.747	2
Meter II				Steel fittings			
NA	(0.252, 0.872, 0.196)	5.902	4	ES	(0.325, 0.822, 0.180)	0.249	1
KA	(0.338, 0.859, 0.206)	6.214	2	GA	(0.289, 0.868, 0.192)	−0.004	3
MA	(0.350, 0.846, 0.184)	6.181	3	FI	(0.301, 0.860, 0.187)	0.065	2
EL	(0.361, 0.843, 0.189)	6.334	1				

occasion also underlined the accuracy and propriety of the decision to employ SFS linguistic terms and mathematical operation functions in computations to reflect the human judgement and vagueness in the benchmarking process and to investigate the multicriteria variable structure of the addressed problem with a group decision making approach which enables scientific researchers to include judgements and experience of more than one DM particularly in this kind of multidimensional complex problems.

4.3. Sensitivity Analysis. A series of sensitivity analysis experiments were carried out to survey the performance of the proposed approach and analyze the influence of differing perspectives on the solution space structure. Six different scenarios were developed in these aims including the main application scenario, where, two of the new scenarios represent the existence of contentious situations, two represent the existence of a dominant DM perspective, and one represents the existence of two different dominant DM perspectives. Comprehensive information about the developed scenarios were presented in details, hereinafter.

T_{11}: Equal dominance levels for all DMs (w_{D1}: 0.333; w_{D2}: 0.333; w_{D3}: 0.333) (*main application case*)

T_{21}: Contentious situation-I (w_{D1}: 0.6; w_{D2}: 0.1; w_{D3}: 0.3)

T_{22}: Contentious situation-I (w_{D1}: 0.1; w_{D2}: 0.3; w_{D3}: 0.6)

T_{23}: Contentious situation-I (w_{D1}: 0.3; w_{D2}: 0.6; w_{D3}: 0.1)

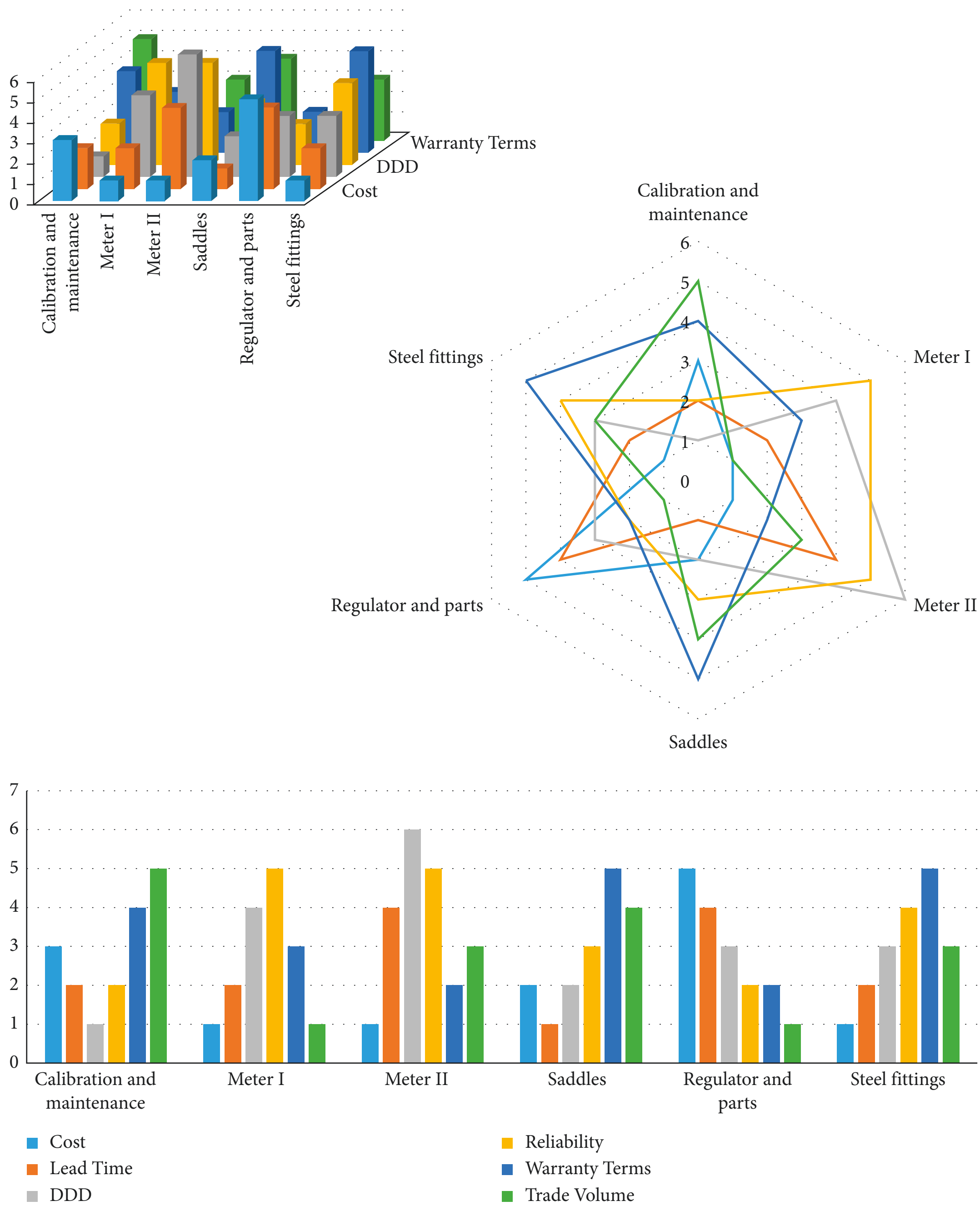

Figure 4: Influence of decision criteria according to different item groups.

T_{31}: Contentious situation-II (w_{D1}: 0.5; w_{D2}: 0.3; w_{D3}: 0.2)

T_{32}: Contentious situation-II (w_{D1}: 0.2; w_{D2}: 0.5; w_{D3}: 0.3)

T_{33}: Contentious situation-II (w_{D1}: 0.3; w_{D2}: 0.2; w_{D3}: 0.5)

T_{41}: Existence of a dominant DM-I (w_{D1}: 0.7; w_{D2}: 0.1; w_{D3}: 0.2)

T_{42}: Existence of a dominant DM-I (w_{D1}: 0.2; w_{D2}: 0.1; w_{D3}: 0.7)

T_{43}: Existence of a dominant DM-I (w_{D1}: 0.1; w_{D2}: 0.2; w_{D3}: 0.7)

T_{51}: Existence of a dominant DM-II (w_{D1}: 0.8; w_{D2}: 0.1; w_{D3}: 0.1)

T_{52}: Existence of a dominant DM-II (w_{D1}: 0.1; w_{D2}: 0.1; w_{D3}: 0.8)

T_{53}: Existence of a dominant DM-II (w_{D1}: 0.1; w_{D2}: 0.8; w_{D3}: 0.1)

T_{61}: Existence of two dominant DMs (w_{D1}: 0.4; w_{D2}: 0.4; w_{D3}: 0.2)

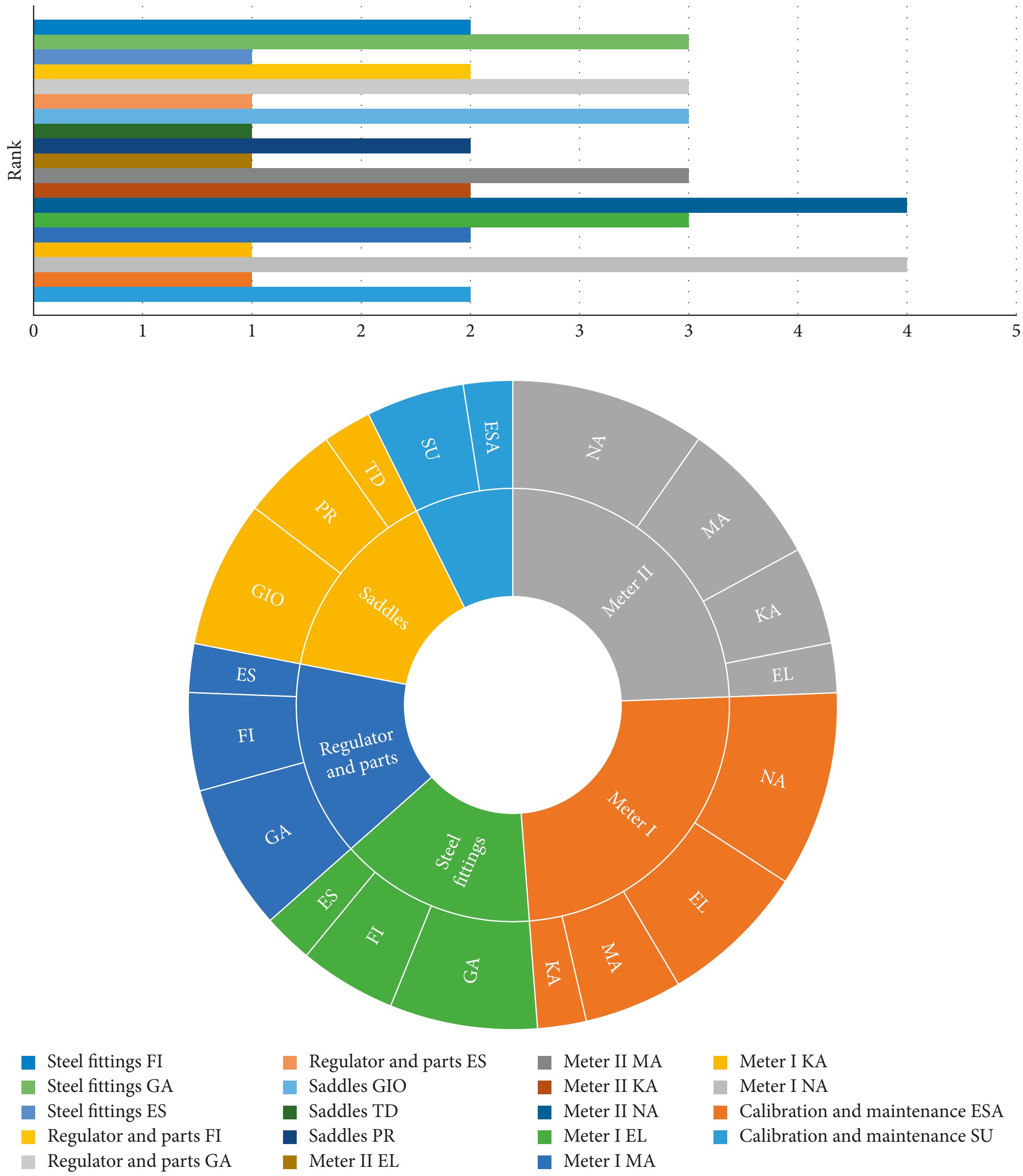

Figure 5: Modification on preference of alternatives according to different item groups.

T_{62}: Existence of two dominant DMs (w_{D1}: 0.4; w_{D2}: 0.2; w_{D3}: 0.4)

T_{63}: Existence of two dominant DMs (w_{D1}: 0.2; w_{D2}: 0.4; w_{D3}: 0.4)

In order to examine these six scenarios developed for the sensitivity analysis application, 15 additional calculation runs (T_{tf}, t: 1, ..., 6; f: 1, ..., 3) were performed for six alternative OHS risks related inventory items purchased from varying suppliers (x_{ij}, i: 1, ..., 6; j: 1, ..., 4) through three DM perspectives (D_d, d: 1, 2, 3). Acquired solution results are epitomized in Tables 12–14 and Figure 6.

Tables 12 and 13 summarize the variation on the final alternative scores, and Figure 6 illustrates the variation on overall criteria weight results schematized upon the data presented in Table 14 according to the diverse dominance levels of differing DM perspectives, respectively. As a result of the sensitivity analysis experiments performed through the scenarios created depending on the different impact values assigned to several DM perspectives, changed alternative priority orders are indicated in bold in Table 13.

As Tables 12 and 13 indicated, the superiority degree of the alternatives represented with a_j values almost does not change depending on the modifications experienced on the DM assessments importance, or, weighting scores. Likewise, it is seen that the importance scores of the decision criteria represented by w_k values, that is, their power to influence the decision process are also not influenced by the modifications

Table 12: Variance of final alternative score a_j results.

	a_j values															
	T_{11}	T_{21}	T_{22}	T_{23}	T_{31}	T_{32}	T_{33}	T_{41}	T_{42}	T_{43}	T_{51}	T_{52}	T_{53}	T_{61}	T_{62}	T_{63}
Calibration and maintenance																
SU	−0.30	−0.31	−0.29	−0.22	−0.28	−0.25	−0.33	−0.27	−0.19	−0.31	−0.23	−0.34	−0.14	−0.27	−0.33	−0.28
ESA	0.13	0.20	0.20	0.06	0.13	0.09	0.18	0.21	0.04	0.25	0.22	0.32	0.03	0.10	0.17	0.12
Meter I																
NA	0.03	0.00	0.09	0.03	0.00	0.05	0.04	−0.01	0.05	0.10	−0.01	0.11	0.08	0.01	0.02	0.06
KA	0.27	0.19	0.38	0.28	0.22	0.32	0.29	0.16	0.32	0.39	0.15	0.41	0.37	0.25	0.25	0.32
MA	0.23	0.14	0.40	0.21	0.15	0.29	0.28	0.10	0.26	0.42	0.07	0.44	0.32	0.19	0.22	0.31
EL	0.13	0.11	0.08	0.24	0.16	0.17	0.09	0.13	0.27	0.05	0.15	0.03	0.31	0.17	0.10	0.13
Meter II																
NA	−0.17	−0.17	−0.14	−0.17	−0.18	−0.17	−0.16	−0.18	−0.17	−0.13	−0.19	−0.12	−0.16	−0.17	−0.16	−0.16
KA	0.26	0.23	0.26	0.30	0.25	0.29	0.24	0.23	0.32	0.25	0.23	0.24	0.34	0.27	0.24	0.27
MA	0.35	0.40	0.33	0.32	0.37	0.33	0.36	0.40	0.31	0.34	0.41	0.35	0.29	0.35	0.37	0.33
EL	0.42	0.39	0.50	0.39	0.38	0.43	0.45	0.36	0.40	0.52	0.34	0.54	0.42	0.39	0.42	0.45
Saddles																
PR	0.05	0.04	0.02	0.11	0.06	0.07	0.02	0.06	0.13	0.01	0.07	0.00	0.15	0.07	0.03	0.05
TD	0.46	0.62	0.38	0.43	0.53	0.39	0.47	0.67	0.39	0.39	0.72	0.41	0.35	0.48	0.51	0.40
GIO	0.53	0.56	0.53	0.52	0.54	0.51	0.54	0.57	0.50	0.55	0.58	0.59	0.49	0.53	0.54	0.52
Regulator and parts																
ES	0.02	−0.01	0.07	0.00	−0.01	0.03	0.04	−0.02	0.01	0.08	−0.03	0.09	0.02	0.00	0.02	0.04
GA	0.27	0.25	0.27	0.28	0.26	0.27	0.26	0.25	0.28	0.27	0.26	0.26	0.29	0.27	0.26	0.27
FI	0.15	0.18	0.12	0.16	0.17	0.14	0.14	0.20	0.16	0.12	0.22	0.12	0.15	0.16	0.15	0.13
Steel fittings																
ES	0.25	0.24	0.25	0.28	0.25	0.26	0.24	0.24	0.29	0.24	0.25	0.24	0.30	0.26	0.24	0.25
GA	0.00	0.06	−0.05	0.00	0.04	−0.03	−0.01	0.09	−0.02	−0.05	0.14	−0.05	−0.04	0.02	0.01	−0.03
FI	0.07	0.07	0.00	0.15	0.10	0.08	0.02	0.09	0.16	−0.03	0.12	−0.05	0.17	0.11	0.04	0.05

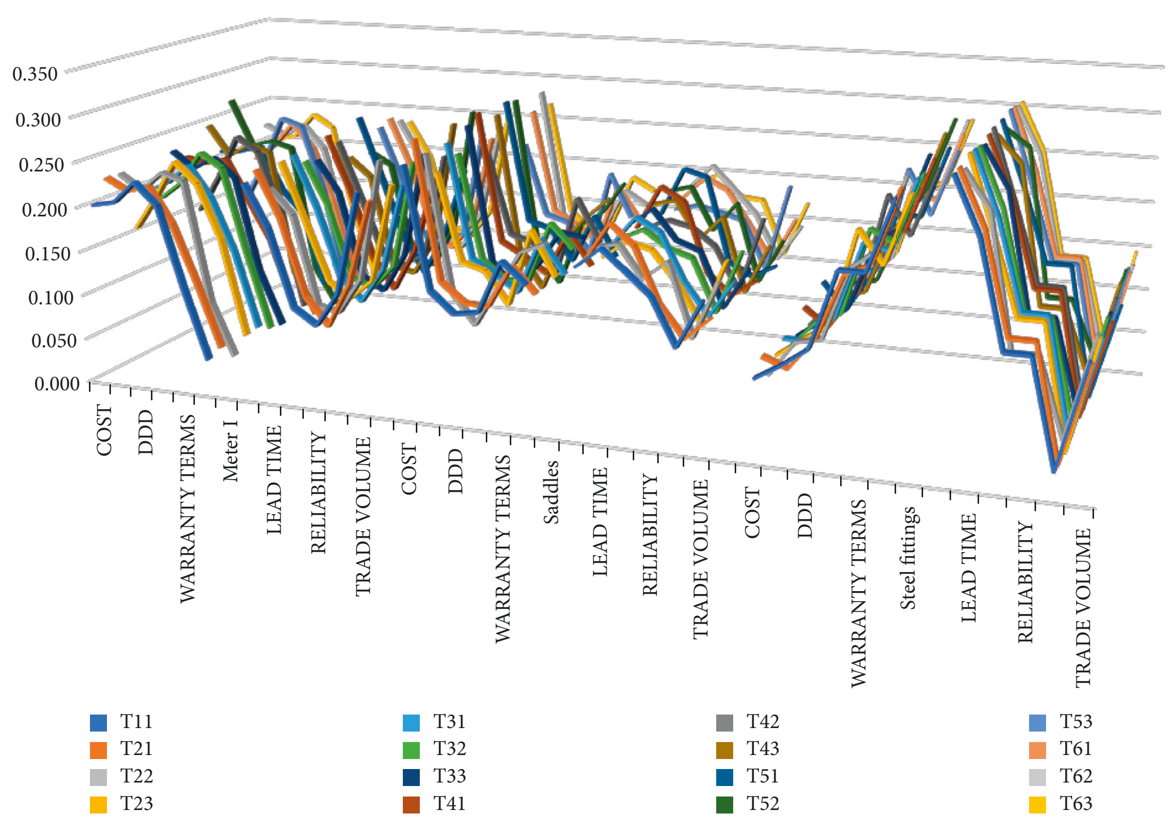

Figure 6: Variance of criteria weights according to w_k values in terms of developed scenarios.

Table 13: Variance of final ranks of alternatives.

	Ranks															
	T_{11}	T_{21}	T_{22}	T_{23}	T_{31}	T_{32}	T_{33}	T_{41}	T_{42}	T_{43}	T_{51}	T_{52}	T_{53}	T_{61}	T_{62}	T_{63}
Calibration and maintenance																
SU	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
ESA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Meter I																
NA	4	4	3	4	4	4	4	4	4	3	4	3	4	4	4	4
KA	1	1	2	1	1	1	1	1	1	2	2	2	1	1	1	1
MA	2	2	1	3	3	2	2	3	3	1	3	1	2	2	2	2
EL	3	3	4	2	2	3	3	2	2	4	1	4	3	3	3	3
Meter II																
NA	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
KA	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3
MA	2	1	2	2	2	2	2	1	3	2	1	2	3	2	2	2
EL	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	1
Saddles																
PR	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
TD	2	1	2	2	2	2	2	1	2	2	1	2	2	2	2	2
GIO	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	1
Regulator and parts																
ES	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
GA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Steel fittings																
ES	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GA	3	3	3	3	3	3	3	2	3	3	2	2	3	3	3	3
FI	2	2	2	2	2	2	2	3	2	2	3	3	2	2	2	2

in DM assessment importance levels, which are used in reflecting the DMs' judgements into the SFS-SAW calculations (Figure 6).

The results of 15 additive computation runs within six different application scenarios showed that both alternative priorities and criteria importance scores are insensitive to the change in the power of different DM perspectives to influence the computation outcomes has proven that the proposed approach can yield robust, effective, and reliable results by removing the effects of human judgement on the decision making process.

4.4. Managerial Insights and Practical Implications. The purpose of all OHS activities is to protect employees, to ensure production safety and to ensure operational safety. OHS is of great importance in order to follow a regular and prudent pathway in OM implications. The obligation of employers in this regard is to take all measures for OHS risk elimination or minimization and to prevent accidents.

OHS risk minimization activities, which are often associated and carried out with efforts and activities in tactical dimensions, should also be associated with activities carried out on a more strategic basis from a macro perspective. In this way, a broader approach to OHS risk minimization can be developed, where, accidents which could occur in any workplace might be eliminated even before their root-causes were emerged.

This study suggests the employment of a robust novel approach specifically developed for OHS risk minimization to articulate the OHS standpoint with SCM operations through inventory management and B2B relationship management. The proposed approach uses the integrated ABC-VED method to simultaneously consider the severity, cost, and amount parameters of purchased items, where suppliers were also investigated on their performances in terms of OHS risks and basic SCM criteria. Risk assessment procedures bring uncertainty and vagueness to the problem spaces to which they relate by their very nature, where both OHS risk assessment procedures and supplier selection problem require DM insights and assessments as input data. The proposed approach introduced SFS based SAW solution methodology to handle this mentioned uncertainty; correspondingly, the results of the performed case study from energy industries approved the robustness and reliability of the proposed approach.

As indicated with the results, field executives and scientific researchers could depend on the proposed approach with greater peace of mind, where sensitivity analysis results indicated that neither alternative performance scores nor criteria dominance sequence varied in response to the modifications on the weightings of DMs, which means influence levels of DM perspectives on final results. In these regards, this novel approach could be adapted and effectively implemented in many different application fields without being limited to only energy industry, or B2B relationship management activities of SCM practices.

The criteria set identified in this study could be a valuable resource for field practitioners and scientific researchers on energy, petroleum, and, maintenance and repair companies

Table 14: Calculated w_k values for each item group in sensitivity analysis.

	w_j values															
	T11	T21	T22	T23	T31	T32	T33	T41	T42	T43	T51	T52	T53	T61	T62	T63
Calibration and maintenance																
Cost	0.201	0.226	0.225	0.157	0.195	0.181	0.230	0.218	0.148	0.246	0.209	0.267	0.139	0.184	0.222	0.199
Lead time	0.207	0.213	0.209	0.194	0.206	0.200	0.211	0.212	0.190	0.211	0.211	0.213	0.186	0.203	0.211	0.205
Ddd	0.231	0.220	0.230	0.237	0.228	0.237	0.226	0.220	0.240	0.226	0.218	0.220	0.243	0.232	0.226	0.234
Reliability	0.207	0.181	0.223	0.215	0.193	0.221	0.205	0.174	0.225	0.218	0.167	0.213	0.235	0.203	0.198	0.219
Warranty terms	0.117	0.116	0.086	0.153	0.133	0.124	0.095	0.128	0.155	0.075	0.141	0.065	0.157	0.135	0.106	0.110
Trade volume	0.038	0.044	0.027	0.043	0.045	0.036	0.033	0.049	0.041	0.024	0.053	0.022	0.039	0.043	0.038	0.034
Meter I																
Cost	0.240	0.249	0.223	0.248	0.250	0.237	0.233	0.256	0.244	0.220	0.263	0.216	0.241	0.247	0.240	0.234
Lead time	0.192	0.198	0.196	0.183	0.192	0.188	0.197	0.196	0.181	0.199	0.195	0.202	0.179	0.189	0.196	0.191
Ddd	0.108	0.113	0.096	0.116	0.115	0.107	0.102	0.118	0.115	0.092	0.123	0.089	0.113	0.114	0.107	0.104
Reliability	0.091	0.083	0.091	0.099	0.089	0.097	0.087	0.082	0.103	0.088	0.081	0.085	0.107	0.093	0.087	0.094
Warranty terms	0.128	0.132	0.130	0.122	0.128	0.125	0.132	0.131	0.121	0.133	0.130	0.135	0.119	0.126	0.131	0.128
Trade volume	0.240	0.226	0.264	0.231	0.226	0.245	0.249	0.217	0.236	0.269	0.208	0.273	0.241	0.231	0.240	0.250
Meter II																
Cost	0.274	0.296	0.275	0.249	0.276	0.259	0.286	0.295	0.241	0.283	0.293	0.290	0.233	0.268	0.286	0.268
Lead time	0.142	0.145	0.127	0.153	0.150	0.143	0.133	0.151	0.152	0.122	0.156	0.116	0.151	0.149	0.139	0.138
Ddd	0.120	0.124	0.093	0.146	0.135	0.122	0.103	0.136	0.145	0.085	0.148	0.077	0.144	0.135	0.113	0.112
Reliability	0.124	0.123	0.137	0.111	0.117	0.121	0.133	0.118	0.110	0.143	0.113	0.148	0.110	0.117	0.128	0.127
Warranty terms	0.182	0.169	0.179	0.195	0.179	0.190	0.174	0.169	0.200	0.172	0.168	0.166	0.206	0.185	0.175	0.185
Trade volume	0.159	0.142	0.189	0.146	0.142	0.164	0.170	0.132	0.151	0.195	0.122	0.202	0.157	0.147	0.159	0.170
Saddles																
Cost	0.183	0.184	0.190	0.174	0.180	0.180	0.189	0.180	0.173	0.194	0.177	0.198	0.171	0.179	0.186	0.184
Lead time	0.205	0.224	0.197	0.192	0.212	0.193	0.209	0.228	0.184	0.201	0.231	0.205	0.177	0.204	0.213	0.197
Ddd	0.183	0.203	0.161	0.186	0.198	0.174	0.177	0.213	0.178	0.159	0.223	0.157	0.171	0.191	0.186	0.172
Reliability	0.160	0.144	0.183	0.154	0.147	0.166	0.167	0.136	0.159	0.186	0.128	0.190	0.164	0.152	0.158	0.170
Warranty terms	0.109	0.111	0.104	0.112	0.112	0.109	0.107	0.112	0.111	0.102	0.114	0.101	0.110	0.112	0.109	0.107
Trade volume	0.160	0.135	0.165	0.182	0.152	0.178	0.151	0.131	0.194	0.158	0.128	0.150	0.207	0.162	0.148	0.170
Regulator and parts																
Cost	0.086	0.101	0.073	0.086	0.096	0.080	0.084	0.108	0.081	0.073	0.115	0.072	0.076	0.091	0.089	0.079
Lead time	0.103	0.091	0.111	0.106	0.096	0.109	0.103	0.088	0.111	0.110	0.085	0.109	0.115	0.101	0.099	0.108
Ddd	0.122	0.124	0.117	0.124	0.125	0.121	0.120	0.126	0.123	0.116	0.128	0.115	0.121	0.124	0.122	0.120
Reliability	0.204	0.193	0.194	0.226	0.207	0.214	0.192	0.196	0.232	0.186	0.198	0.178	0.238	0.212	0.195	0.206
Warranty terms	0.204	0.206	0.214	0.192	0.200	0.200	0.212	0.202	0.190	0.220	0.198	0.225	0.188	0.198	0.209	0.206
Trade volume	0.280	0.284	0.290	0.266	0.276	0.276	0.289	0.280	0.264	0.296	0.276	0.301	0.261	0.274	0.286	0.281
Steel fittings																
Cost	0.307	0.307	0.300	0.311	0.309	0.307	0.303	0.309	0.311	0.298	0.310	0.295	0.311	0.309	0.306	0.305
Lead time	0.249	0.250	0.263	0.234	0.242	0.245	0.260	0.244	0.232	0.270	0.239	0.276	0.231	0.241	0.255	0.252
Ddd	0.139	0.145	0.123	0.150	0.148	0.138	0.130	0.152	0.148	0.118	0.158	0.114	0.146	0.147	0.137	0.134
Reliability	0.139	0.145	0.123	0.150	0.148	0.138	0.130	0.152	0.148	0.118	0.158	0.114	0.146	0.147	0.137	0.134
Warranty terms	0.027	0.024	0.041	0.018	0.021	0.027	0.034	0.020	0.019	0.046	0.016	0.050	0.019	0.021	0.029	0.031
Trade volume	0.139	0.128	0.150	0.138	0.131	0.144	0.141	0.124	0.142	0.151	0.119	0.151	0.146	0.135	0.137	0.145

serving organizations working on critical lines, as it was identified upon delineated literature surveys and valuable knowledge and experience of the DMs.

Furthermore, researchers and field practitioners can benefit from the SCM and OHS risk minimization aspects by concentrating on criteria that will be determined to be of high importance in their own applications during investment decisions. As other attempts, paying attention to the relationships with the suppliers having the highest performance can again be of great benefit as the eminent results of B2B analysis showed us. It should be noted here that suppliers with a cost win will not always provide the best performance in terms of OHS risk minimization.

The very fruitful results of this study are of versatility and depth that can provide benefit to experts and DMs, as well as scientific researchers, operating in the relevant field.

5. Conclusions

A novel approach for minimizing OHS risks through inventory control applications in regards with SCM OM and B2B relationship development activities was proposed in this study, with the employment of integrated ABC-VED analysis and SFS-based SAW method. A real-world case study related to the leader gas distribution company of Turkish energy sector was performed, and effectiveness, agility, and accuracy of the proposed approach was demonstrated.

The protoset of 270 different items to be purchased and 197 to be inventoried was eliminated to 103 inventoried items which corresponds with OHS risks and might cause adverse impacts on human health. Integrated ABC-VED analysis identified the most critical item group as 51 items listed in Category I in regards with OHS risk minimization target, where that subset of items was also divided into six item groups according to the supplier companies to develop B2B relationship management strategies.

Group decision-making approach and fuzzy sets were employed to handle the complexity and vagueness of the decision space. The varying criteria weights and the best-performing companies among contestants were delineated in terms of each item group; furthermore, results were interpreted separately and comparatively in terms of final ranking scores, diverging impact domains regarding different DMs' assessments as further analysis. Sensitivity analysis were also performed to evaluate the influence of different DM perspectives on the overall results and solution space structure. Subsequently, managerial strategies and suggestions for practical implications were addressed in lieu with the study outcomes. A brief summary of the performed analysis, results, and yielded benefits are listed below for convenience of the readers.

A standpoint connecting ergonomics science and OHS measures to SCM and OM activities was constructed.

(i) SFS was introduced to SCM-OM decision processes.

(ii) OHS risk minimization target was handled with inventory management activities.

(iii) Integrated ABC-VED inventory management technique was introduced to energy industries.

(iv) Criteria importance levels were identified with SFS-SAW computations to be able to handle the uncertainty of the process, grounding on OHS risk minimization main target.

(v) As results, "Damaged/delinquent delivery" ($w_k = 0.231$), "Trade volume" ($w_k = 0.240$), "Cost" ($w_k = 0.272$), "Lead time" ($w_k = 0.205$), "Trade volume" ($w_k = 0.0.280$), and "Cost" ($w_k = 0.307$) criteria were found to have the highest importance in B2B relationship management regarding OHS risks minimization for corresponding item groups "Calibration and Maintenance," "Meter I," "Meter II," "Saddles," "Regulator and Parts," and "Steel Fittings," respectively.

(vi) "ESA," "KA," "EL," "TD," and "ES" supplier companies were selected to perform best regarding the corresponding item groups in terms of OHS risk minimization target grounding on the identified decision criteria set.

(vii) Sensitivity analysis were performed with 16 computation runs (including the main case study computation) in regards of the developed six different scenarios. As consequence of these experiments, the results did not respond to changes in the input data; hence, the proposed approach has been proven to give reliable results away from influence of human judgements.

The width of DMs set identified to take part in the assessment of the research could be considered as a limitation for this study; hence, as a suggestion for future works, the DM group could be widened by considering different parties of SCM-B2B relationship structure. As another suggestion, different fuzzy sets and linguistic summarization representations could be employed to investigate the diverse influence of linguistic expression projection on the results.

The proposed approach is competent to be utilized as a base model for scientific researchers and field practitioners from differing activity fields and could easily be adjusted for possible other specific application domains in terms of their exclusive point of views or requirements. The proposed approach is also suitable to be used with different MCDM methods than SAW and easily be adapted to differentiated working environments when required [23, 40, 42–44].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Empirical Evaluation of Iranian CIO Perspective with Adoption of Green Information Technology

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In recent decades, green aspects became a key priority for governments worldwide, as sustainable policies are able to promote a more equitable society and a healthier economy from the social, economic, and environmental perspectives, in addition to preserving natural resources for future generations. As an essential context in information technology management, green information technology (GIT) has been developed to cope with the existing environmental problems through organizations. The present study is aimed at identifying the influential factors of decision-making on the adoption of GIT. To collect the required data, interviews were performed along with a structured survey. A total of 112 questionnaires were delivered to chief information officers (CIOs), 99 of which underwent the analysis. The structural equation and partial least square approaches were adopted for data analysis. GIT driver (G-driver) was found to be an intermediary parameter. Findings revealed the GIT readiness (G-readiness) and GIT context (G-context) result in in GIT adoption whenever there was a G-driver indicator (i.e., ethical driver, economic driver, response driver, or regulatory driver). The present study found the significance of all the variables to be above 1.96 except G-context −> green intention to adoption path and G-readiness −> green intention to adoption. Considering that the determination of coefficients and the analysis of relationships between factors directly depends on the opinion of experts and if the opinion of expert's changes, the results will also change; this can be mentioned as the most important limitation of the research. Therefore, it should be noted that the largest impact was identified to be posed by the economical driver.

1. Introduction

Green information and communication technology (ICT) innovations are key to achieving global climate goals. Cross-border technological cooperation has become a strategic choice for countries to achieve technological breakthroughs [1]. Rapid advancement in ICT is promoting us into an era of unprecedented prosperity and countless possibilities. However, there is one gloomy side of the ICT technology that contributes toward the inflation of carbon footprint [2]. Today, the increasing use of technology and the industrial revolution are affecting the economy and the environment, such as the development of economies and the increase of the ecological footprint (EFP) [3]. PERCCOM (PERvasive Computing and COMmunications in sustainable development) Masters is the first innovative international program in green ICT for educating and equipping new IT engineers with green IT skills for sustainable digital applications design and implementation [4]. Today, the assessment of skills in the field of acquiring green skills has increased. In extensive studies, a list of recommendations for environmental development has been provided.

Organizations consider green improvement and environmental sustainability as significant strategic dimensions since they associate with large regulatory, economic, and social pressure [5] and impose challenges to international markets. Furthermore, senior managers have understood the environmental impacts of information technology (IT). They realize that it is important to reduce environmental impacts [6]. IT components have large power consumption rates. The CO_2 emission of IT components is believed to be as high as that in the aviation field [7]. Moreover, climate change and global warming along with energy cost enhancement have imposed a significant challenge on the global economy. To generically respond to such problems, it is required to consider corporate sustainability and corporate social responsibility (CSR) [8].

The term green information and communication technology (green ICT) has been recently employed in academic works and expert papers [9]. It refers to the ability of a corporation to make systematic use of corporate sustainability components for designing, producing, sourcing, utilizing, and disposing of the technological ICT infrastructure as in the managerial and human components of the present ICT infrastructure [10]. In fact, green ICT mainly deals with the environmental impacts posed in the entire lifecycle of IT, including ICT device design, utilization, and management [24]. Today, researchers refer to green ICT as a green approach for most organizations [11].

Green ICT is a key enabler of a green economy [12]. To aid policy makers in promoting green ICT at the national level, this paper proposes a comprehensive understanding of green ICT from the perspective of green innovation for Iranian CIOs and develops an analytical framework based on innovation system approaches. Following the framework, policy makers can formulate policies to solve them. Therefore, green ICT adoption within organizations could be described to be an essential metric of corporate sustainability and success in the economy and green productivity. However, such metrics involve legislation requirements, economic achievements, ethical proofs, and shareholder commitment. Such factors are essential for the study and identification of possibly influential dimensions in green ICT adoption. However, the major factors of adopting green ICT by senior managers and decision-makers in organizations remain yet to be clarified. The present study seeks to realize the readiness factors and metrics that motivate organizations to implement green ICT measures in Iran. The findings of the present work would help explain green ICT adoption in Iranian organizations from an IT management perspective. For this purpose, the main objective of the present study is to extract the influential GIT adoption factors in the views of CIOs in Iranian organizations. Therefore, the main contribution of the research is as follows:

(i) We show the factors that influence the adoption of GIT in Iranian organizations from the point of view of senior managers.

(ii) Development of a model to demonstrate the impact of GIT to provide an efficient package that controls the performance of organizations.

The remainder of the study is organized as follows: Section 2 reviews the literature and background; Section 3 describes the methodology, including statistical processes and analytical framework; Section 4 analyzes the results; Section 5 provides managerial insights of research; and Section 6 concludes the work and makes suggestions.

2. Theoretical Foundations

ICT may have two-way environmental impacts. On the one hand, each ICT lifecycle stage may add to environmental destruction. On the other hand, it is possible that ICT offers a number of suitable instruments to measure, report, and diminish the emissions of greenhouse gases, water utilization, and waste production in core organizations and value chain procedures. GIT typically refers to the utilization of environmental criteria regarding ICT [8]. Gartner [13] proposed a CIO role-based definition of GIT. Most CIOs consider the emission of greenhouse gases and IT order to be the main aspects. More importantly, CIOs help their organizations deal with environmental sustainability at the enterprise scale. However, they also offer analytical instruments, technical/analytical understandings, and leading the changes in the current data centers [8]. The decisions of a CIO influence the entire organization since IT systems currently drive every business process in organizations. Mangal [14] suggested that CIOs would be a primary shareholder in the environmental footprint improvement of organizations. They believed that CIOs could make a significant contribution to planet sustainability improvement. IT is the main factor of environmental footprint in organizations. However, the proper management of IT could yield solutions helping diminish not only the environmental footprints in organizations but also the costs. By implementing effective calculations and a focus on unique opportunities, IT managers establish green investment solutions. Furthermore, senior IT officers have significant data analysis capabilities. Thus, they codify, formulate, and implement green solutions. IT managers perform green intellectual leadership in their organizations and receive significant support. To achieve sustainability commitment in activities, CIOs and green policies should be employed in organizations. To meet environmental criteria and cope with the associated concerns, CIOs investigate practices and policies fitting the requirement of the organization prior to technology decision-making. This has a strong influence on the environmental footprint of the organization. To this end, organizations require green techniques and technologies allowing for the evaluation, management, and reduction of energy consumption as well as w-waste production [15].

The utilization of IT has heavily enhanced the water consumption of organizations. Datacenter cooling accounts for the largest portion of water consumption in organizations. Energy consumption evaluation in an organization enables the CIO to realize how water consumption could be diminished. The saving of water could bring substantial cost and energy savings. There are several technologies, including waterside and airside economization, to evaluate and monitor water consumption. Furthermore, a number of recently developed servers make use of innovative cooling techniques, including built-in pumps and muffins. This property reduces the consumption of water. DC power could also be applied to data centers for water and energy consumption reduction [16]. It is also possible to decrease water consumption in organizations by the reuse of strongly treated wastewater to cool data centers and meet other water demands in IT-intense corporate settings.

Additionally, to reduce the environmental footprint of organizations, it is important that CIOs safely dispose of IT devices with e-waste (e.g., cartridges, laptops, and computers). This is of particular importance concerning short-lifecycle IT devices. It is not reasonable to throw e-waste into the trash and dispose of it within landfills since toxic substances could seep from such waste into water resources. The IT management contributions to the creation and utilization of green technology solutions could be classified into three groups, including the following:

(1) responsibility for IT effectiveness and efficiency through green strategy identification within the organization,

(2) supporting and implementing green measures and plans across the organization, and

(3) working for business benefits as intellectual leaders by deriving optimal solutions from GIT and the realization of GIT strategies.

2.1. Literature Review

2.1.1. Review. GIT is multifaceted in nature. Thus, researchers have proposed a large number of theories and frameworks, including adoption. Adoption-related studies focus on the process of adopting and implementing GIT along with internal and external factors motivating and affecting the adoption of GIT. For example, the technology-organization-environment (TOE) framework was developed as a popular theory. It suggests that three factors influence the adoption and deployment of innovative technologies in organizations. Such groups include environmental, organizational, and technological factors [17]. A large number of studies on new technology adoption employed TOE in several fields, including GIT [18], e-commerce [19], and e-business [20, 21].

The models developed concerning technology adoption deal with technological determinations of innovation adoption and diffusion. Despite possible similarities, green technology adoption differs from the adoption of other technologies in some aspects [22]. Researchers have traditionally considered environmental compliance to impose an additional cost on businesses. Thus, managers have concerns about the possible negative impacts of these initiatives on the competitiveness of their businesses [23]. For the explanation of GIT adoption, it is required to take into account the entire adoption domains. A review of the literature on the adoption of e-commerce, IT, green technologies, and innovations revealed that researchers have proposed several models for the adoption of GIT on the grounds of the IT adoption literature. For example, Zahng and Liang [18] proposed a framework based on innovation system approaches for promoting green ICT in China. For this purpose, a comprehensive understanding of green ICT from the perspective of green innovation is proposed and an analytical framework based on innovation system approaches is developed. Papoli et al. [2] presented a comprehensive survey on green ICT. For this purpose, the survey discussed both aspects of ICT, i.e., green of ICT and green by ICT. Firstly, the recent approaches for the greening of ICT include techniques for green data center and green mobile networks. Li et al. [1] investigated the structural characteristics and influence mechanism of green ICT transnational cooperation network. For this purpose, 49,731 patents used social network analysis method (SNA) and quadratic assignment procedure (QAP) to discuss the structural features and influence mechanisms of the worldwide green ICT cooperation network from 2000 to 2019. Kahouli et al. [3] investigated the relationship between ICT, green energy, total factor productivity, and ecological footprint. For this purpose, we focused on the Kingdom of Saudi Arabia (KSA) to assess the impact of ICTs, green energy (renewable energy and electric power consumption), and economic activities (total factor productivity: TFP) on the environmental quality (EFP) by applying the Johansen cointegration technique and vector error correction method (VECM). Ofori et al. [24] examined the direct and indirect effects of ICT diffusion on inclusive growth in 42 Africa countries over the period 1980–2019. Robust evidence is provided to several specifications from the dynamic system GMM to show that (i) ICT skills, access, and usage induce inclusive growth in Africa countries and (ii) the effects of ICT skills, access, and usage are enhanced in the presence of financial development. Evangelista and Hallikas [25] explored the influence of ICT adoption on sustainability practices in purchasing and supply management (PSM) as well as its effects on purchasing performance. To accomplish this objective, a comprehensive review of the literature was conducted. A number of such works are summarized in Table 1.

2.1.2. GIT Context. The context of GIT evaluates the current features of technology adoption frameworks. In TOE, such contexts are classified by GITAM into three contexts, including environmental, technological, and organizational. GIT has distinct intention to use and actual adoption since research has recently shown that a number of managers in organizations need to implement robust measures, even when they have environmental concerns and intend to take actions accordingly [22, 3]. Thus, there is a gap between awareness and action.

Concerning the technological context, it should be noted that GIT is expected to flourish wherever significant IT assets have been implemented. The pressure of power cost enhancement and the challenge of housing, cooling, and powering technologies are greater where high-density servers are employed. As a result, servers of higher energy efficiency and/or the virtualization and consolidation of

Table 1: A summary of GIT adoption works.

Author(s)	Paper	Method
[18]	Promoting green ICT in China: a framework based on innovation system approaches	Structural equation model
[26]	Drivers for green IT in organizations: multiple case studies in China and Singapore examining the drivers for green IT initiatives of companies in the Asia Pacific region	Bibliography
[27]	GIT adoption: a managerial perspective to investigate how organizational factors affect the formation of an organizational decision maker's intention to green IT adoption through the mediation of managerial perceptions	Structural equation model
[28]	A research agenda on managerial intention to green IT adoption: from norm activation perspective, the current study adopts a norm activation model in organizational context to investigate how an intention to green IT adoption is formed (norm activation model (NAM))	Structural equation model
[29]	Organizational green IT adoption: concept and evidence They provided a comprehensive review to explain the reasons for GIT adoption in organizations	Bibliography
Alemayehu Molla and Ahmad Abareshi [30]	Organizational green motivations for information technology: empirical study	Structural equation model
Shaun Thomson and Jean-Paul van Belle [31]	Antecedents of GIT adoption in south African higher education institutions	Structural equation model
[32]	GIT adoption: influential factors and extension of planned behavior theory	Structural equation model
[2]	A comprehensive survey on green ICT with 5g-Nb-iot: towards sustainable planet	Bibliography
Kahouli et al., 2022	Investigating the relationship between ICT, green energy, total factor productivity, and ecological footprint: empirical evidence from Saudi Arabia	Structural equation model
[1]	Research on the structural features and influence mechanism of the green ICT transnational cooperation network	Bibliography
Ofori et al. [24]	Inclusive growth in sub-Saharan Africa: exploring the interaction between ICT diffusion and financial development	Structural equation model
Evangelista and Hallikas [25]	Exploring the influence of ICT on sustainability in supply management: evidence and directions for research	Bibliography

servers could be adopted [33]. The utilization of green logistics and manufacturing techniques also falls in the technological context.

The organizational context deals with the descriptive business characteristics, including corporate citizenship, size, and sector. Sectors may make different responses to GIT. As it is directly involved in environmental policies, a utility company (e.g., a power, gas, or oil company) is a more probable candidate of early GIT adoption.

Regarding the environmental context, it is worth noting that TOE involves regulatory settings as an essential component for the creation of permissive and conductive settings to promote the utilization of GIT measures. Governmental organizations may promote GIT adoption through legislation enabling a low-carbon economy.

2.1.3. Green IT Drivers. An economic driver represents the necessity of higher IT efficiency and pursing significant savings in costs in IT operations. Global business expansion and storing numerous data copies for regulation compliance and meeting strategies implemented for the continuity of businesses substantially enhance data storage. Corporate data amounts increased above 10^6 TB in 2007. It was estimated to rise above 1 ZB in 2010 (IDC in Brocade, 2007). Economic drivers such as cost diminishing are among substantial GIT drivers [34]. Due to increased energy costs, energy consumption reduction is known as a major ICT-related cost reduction strategy [35, 36].

Regulatory drivers (including regulatory adherence) make essential contributions to the organizational intention to adopt GIT. Organizations are required by specific regulations to provide CO_2 emission reports above a predefined level [18, 48]. More importantly, actions arising from the necessity of meeting certain regulations (either voluntary or mandatory ones) are emphasized. GIT guidelines have been developed by some intergovernmental, professional, and national organizations. Some organizations may not intend to adopt GIT. Regulatory driver predominance could result in a minimalistic approach to the adoption of GIT. It may promote GIT practices, such as IT procurement of environmental preference, IT carbon footprint evaluation, green power proportion enhancement, and IT end-of-life (EoL) management. The ethical driver represents pursuing business exercises of social responsibility and good corporate citizenship. Given that the green movement influences the entire corporate life aspects, organizations increasingly attempt to be socially recognized to be concerned about social responsibility in both local and global communities [37]. Businesses make use of CSR initiatives for enhancing their brand awareness among crucial shareholders, such as the general public, consumers, and investors [38]. It is reasonable to view self-motivation as an ethical driver in GIT implementation. GIT could be implemented on the grounds of the overall beliefs and perception of organizations for doing the common good. This could arise from the understanding of the cost benefits for gradually establishing confidence among the employees or even directing the ambitions and hopes toward brand image improvement [39].

2.1.4. Response Drivers. Market opportunities involve the increasing knowledge of the environmental impacts of ICT and the consideration of ICT to be an approach to dealing with those impacts. Today, businesses can implement sustainable ICT measures and supply green ICT software and equipment [36, 40]. Political, cultural, and social pressure may serve as a great driver for the awareness of GIT and, consequently, its adoption. This could occur whenever environmental degradation is appreciated by society, realizing its essentiality. This would drive organizations to adopt different approaches [36]. It is also possible that an organization is obliged to adopt GIT measures to meet industrial requirements (of other enterprises). The adoption of sustainable techniques by an organization invariably drives other related organizations to implement sustainable exercises [36]. Molla and Abareshi [41] proposed response drivers by integrating the political, cultural, and social drivers with industry and market opportunity drivers.

2.1.5. GIT Readiness. GIT readiness dynamically evaluates the preparation of the environment and organizations to adopt GIT. It involves perceptual features in the context of adoption. It was suggested that the same number of organizational and external environment characteristics appear to be secondary as the number of innovation characteristics known to be secondary [42]. Based on this suggestion, Molla and Licker [43] argued that two organizations with the same organizational resource level and context may differently perceive the readiness level and differently make decisions on adoption. Thus, one can extract three GIT readiness dimensions from the PERM of Molla and Licker [43] including institutional, value-network, and organizational dimensions.

Organizational GIT readiness refers to the GIT-related resources, commitment, and awareness of an organization. The degree of concerns about the social and environmental IT has an impact on business and IT leaders services as an essential factor for GIT initiation.

Moreover, value-network GIT readiness represents to what extent the suppliers, consumers, investors, and rivals of a company are ready for GIT. Concerning the readiness of suppliers, some vendors perform the marketing of their products as green measures. IT vendors are at the center of GIT agendas [44].

Regarding government GIT readiness, it should be noted that governments can have effects on GIT via rendering direct subsidies. Since governments are major IT users, they can serve as leaders and develop a norm for the utilization of GIT. Professional institutions commonly make use of significant influence concerning professional exercises. In turn, this could have GIT adoption implications.

2.1.6. Research Gap. According to the previous study, the present study developed a theoretical model on the basis of GITAM proposed by Molla [18]. Molla [18] sought to propose a novel theory on GIT adoption on the grounds of the available adoption and innovation frameworks. GITAM combined two models in the form of theoretical background. PERM and TOE were built as second-order facilitating components. It was argued that drivers (i.e., strong-order reasons), in combination with these components, could affect the GIT adoption process and content. For the identification of GIT divers, earlier works developed the organizational motivation theory, as shown in Figure 1 [45]. GITAM suggests that GIT drivers, GIT context, and GIT readiness affect the intention of organizations to adopt GIT.

3. Methodology

As it sought to extract factors that impact GIT adoption from an IT management perspective, the present study has applied research in terms of objectives. Furthermore, the findings of the present work could be helpful to organizations in reducing costs and environmental impacts through the green management of IT. As this study provides a representation of the current situation, it adopts a descriptive methodology. Data were collected using questionnaires. Therefore, the present study is a survey. This study is a correlational research in terms of data analysis and employs the structural equation method (SEM). The scale of the data is sequential since the Likert scale was applied. The statistical population consisted of IT managers in governmental and private organizations.

To calculate the content and face validity of the questionnaire, content validity index (CVI), and content validity ratio (CVR), the views of twelve experts were exploited. Furthermore, Cronbach's alpha was employed to evaluate questionnaire reliability. It was calculated for twenty respondents. Alpha was found to be above 0.75 for the entire variables. The measurement instrument of the variables was concluded to be sufficiently and property reliable.

Once the respondent characteristics had been described by descriptive statistical indexes, partial least square-structural equation modeling (PLS-SEM) was applied to analyze the responses. As a multivariate method, PLS-SEM has recently been popular [46]. It is a strong and competent instrument that applies few constraints on the measurement scales. PLS-SEM helps model nonnormal latent constructs [47]. To carry out PLS-SEM, the validity and reliability of the measurement model should be ensured. Also, ordinary least square regression is noniteratively applied to derive the outer weights, structural relationships, and loads of manifest and latent constructs. Eventually, bootstrap resampling is employed for the statistical significance evaluation of the paths.

Google forms were employed to deliver the questionnaires. CIOs received the questionnaires during April-September 2017. The selected CIOs were IT experts, including senior managers at IT companies and IT faculties. A total of 112 collected responses were subjected to reliability and usability screening.

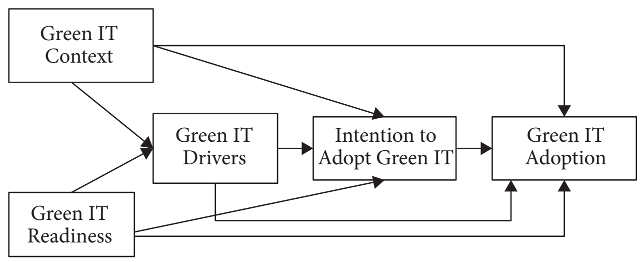

Figure 1: Basic GITAM framework [18].

3.1. Data Analysis Method. The proposed framework for establishing the proposed model in this research, which is based on structural equations, is generally possible in four stages as follows:

(1) Identify effective factors of CIO Perspective in GIT
(2) Determine the impact of each factor on CIO Perspective in GIT
(3) Calculate the degree of relationship between observe and latent factors
(4) Introduce a structural equation model and how to convert the current situation to the proposed desired situation

Phase 1. Identify effective factors of CIO Perspective in GIT.

Tool: questionnaire.

In this step, we first divide the influencing factors into two groups of observed and hidden variables. Observed variables are those variables that are determined using an internal systematic study as criteria that can affect the organization's process. Studying the observed variables in organizations is important because it can always be useful for the analyst in identifying the hidden variables of the organization in question. But in order to study and perform statistical analysis, we must divide these variables into groups, so that we put the observed variables that are related to each other in one category, which are actually the same hidden variables. In this case, the latent variables cover the observed variables. It should be noted that in conceptual model design, hidden variables are always like model nodes. To achieve these variables, the use of data collection tools is a key factor. Questionnaire in this field can be of great help to an analyst. Before preparing the questionnaire, the necessary information should be collected using the library method. To complete this section, by reading books, articles, and research in the relevant field, the most important obvious variables can be found in this regard.

Phase 2. Determine the impact of each factor on CIO Perspective in GIT.

Tools: LISREL software.

This stage is implemented with the aim of providing a conceptual model of the organizational process that can show the relationships between factors well. In other words, at this stage we seek to determine the logical relationships between the hidden variables and other variables. Latent variables are divided into dependent variables and independent variables. Coefficients are actually what we are looking to calculate, based on which the relationship of variables is measured. The coefficient of an independent latent variable is equal to λ, the coefficient of an independent latent variable is equal to γ, and the coefficient of a latent variable is equal to β. If the coefficient is less than 0.3, the relationship is considered weak and we ignore that relationship. A factor loading between 0.3 and 0.6 is acceptable, and a factor loading greater than 0.6 is considered very favorable. The purpose is to determine the coefficients between the variables identified in the organization. For this purpose, a preliminary conceptual model should be designed at this stage.

Phase 3. Calculate the degree of relationship between observe and latent factors.

Tools: LISREL software.

At this stage, after designing the initial model in LISREL software and running the implementation from the initial model, the coefficients are determined by the software if the variables and the model have adequate overlap. At this stage, it is necessary to report the output of the software in different modes such as ESTIMATED and STANDARD to check the estimated coefficients.

Phase 4. Introduce a structural equation model and how to convert the current situation to the proposed desired situation.

In this step, according to the output of LISREL software, the value of P statistic for the model is calculated. Considering that the statistical analysis is performed in the 95% confidence interval; if the *P* value is calculated to be less than 0.05, the model is statistically significant. In general, the lower the value of P, the better. Therefore, it can be concluded that the estimated model has good accuracy. In the ESTIMATED mode, if the variables have the interval range specified in the second phase, we select and leave the other variables. Finally, the path that leads us to the goal is chosen as the dominant strategy over other strategies.

4. Findings

According to the observed cases, the influencing factors on Iranian CIO have been identified from the perspective of GIT. Based on that, hypotheses and subhypotheses are considered as follows:

The main hypotheses are as follows:

H13: GIT readiness has a positive effect on the intention to adopt GIT.

H14: GIT context has a positive effect on the intention to adopt GIT.

H15: GIT drivers have a positive effect on the intention to adopt GIT.

The main subhypotheses are follows:

H1: Professional and governmental institutions have a positive effect on GIT readiness.

H2: Organizational, technologies, monitoring, governance, strategy, policies, and attitude have a positive effect on GIT readiness.

H3: Value network GIT readiness perception influences GIT readiness perception.

H4: Environmental context has a positive effect on GIT context.

H5: Organizational context has a positive effect on GIT context.

H6: Technological context has a positive effect on GIT context.

H7: Economic benefits have a positive effect on GIT drivers.

H8: Ethical organizational beliefs have a positive effect on GIT drivers.

H9: Response drivers have a positive effect on GIT drivers.

H10: Regulatory has positive effects on GIT drivers.

H11: GIT readiness has a positive effect on GIT drivers.

H12: GIT context has a positive effect on GIT drivers.

To perform PLS-SEM, model block unidimensionality should be investigated. A unidimensional block is characterized by Cronbach's alpha and composite reliability (CR) above 0.7 [47]. These values are reported in Table 2. As can be seen, Cronbach's alpha was found to be in the range of 0.70–0.95, while CR was calculated to be 0.92–0.96. Thus, the values are all above 0.7. Furthermore, the estimation results of the measurement model (i.e., average variance extracted (AVE), outer loads, and outer weights) are provided in Table 3. Outer loads stand for the loads of reflective manifest variables and their respective latent variables. They help evaluate the reliability of individual items. A load above 0.7 demonstrates the reliability of the corresponding item [48]. The present study calculated the entire outloads to be above 0.7. AVE is employed for evaluating convergent validity. The present work obtained AVE to be 0.55–0.80 for the variables. As can be seen, AVE was greater than 0.5. Also, the AVE squared roots of the constructs were derived to be above the construct correlations. Once the measurement model had been validated, the structural model was estimated to relate the latent variables.

Figure 2 illustrates the path coefficients of the endogenous latent variables along with the corresponding coefficient of determination (R^2). H1 and H2 were supported by the empirical findings. However, H3 was not supported.

Once the measurement models were examined, the proposed structural model was investigated. Unlike the measurement model, the structural model associates with the latent variables rather than the observed variables; the latent variables are related in this phase. To evaluate the fitness of the proposed structural model, a number of criteria were incorporated, including the significance coefficient (i.e., t-values). The significance coefficient was calculated using bootstrapping in Smart PLS. To fit the structural model via coefficient calculation, the obtained values should be above 1.96. In such a case, the significance is verified at a confidence level of 0.95%. The present study found the significance of all the variables to be above 1.96 except G-context –> green intention to adoption path and G-readiness –> green intention to adoption.

Considering the exclusion of the removed paths, the final model for Iranian CIOs from the perspective of GIT is according to Figure 3.

The quality index of the structural model represents its ability to forecast observed variables based on the corresponding latent variables. The main model involves both the structural and measurement models. The fitness verification of the model completes the fitness test. For the fitness evaluation of a model, the goodness of fit (GOF) index is employed. A GOF of 0.01, 0.20, and 0.36 represents weak, moderate, and strong goodness of fit. These values stand for

Table 2: CR, Cronbach's α, and AVE.

	Cronbach's α	CR	AVE
Economical driver	0.847	0.908	0.766
Environmental context	0.803	0.884	0.718
Ethical driver	0.733	0.834	0.628
G-context	0.893	0.919	0.627
G-drivers	0.897	0.919	0.551
G-readiness	0.943	0.951	0.622
Government	0.851	0.910	0.771
Green intention to adoption	0.868	0.919	0.791
Organizational readiness	0.854	0.896	0.633
Organizational context	0.701	0.803	0.578
Regulatory driver	0.903	0.932	0.775
Response driver	0.703	0.821	0.697
Technological context	1	1	1
Value network	0.921	0.944	0.808

Table 3: Path coefficients.

Coefficients	t-statistic	P-value	Result
Economical –> G-drivers	17.27	0.001	Confirmed
Environmental –> G-context	20.91	0.001	Confirmed
Ethical driver –> G-drivers	5.84	0.001	Confirmed
G-context –> G-drivers	3.00	0.003	Confirmed
G-context –> green intention to adoption	0.44	0.654	Rejected
G-drivers –> green intention to adoption	14.54	0.001	Confirmed
G-readiness –> G-drivers	2.251	0.025	Confirmed
G-readiness –> green intention to adoption	1.057	0.291	Rejected
Government –> G-readiness	18.809	0.001	Confirmed
Organizational –> G-readiness	18.491	0.001	Confirmed
Organizational context –> G-context	12.998	0.001	Confirmed
Regulatory driver –> G-drivers	20.973	0.001	Confirmed
Response driver –> G-drivers	4.052	0.001	Confirmed
Technological context –> G-context	4.058	0.001	Confirmed
Value network –> G-readiness	17.95	0.001	Confirmed

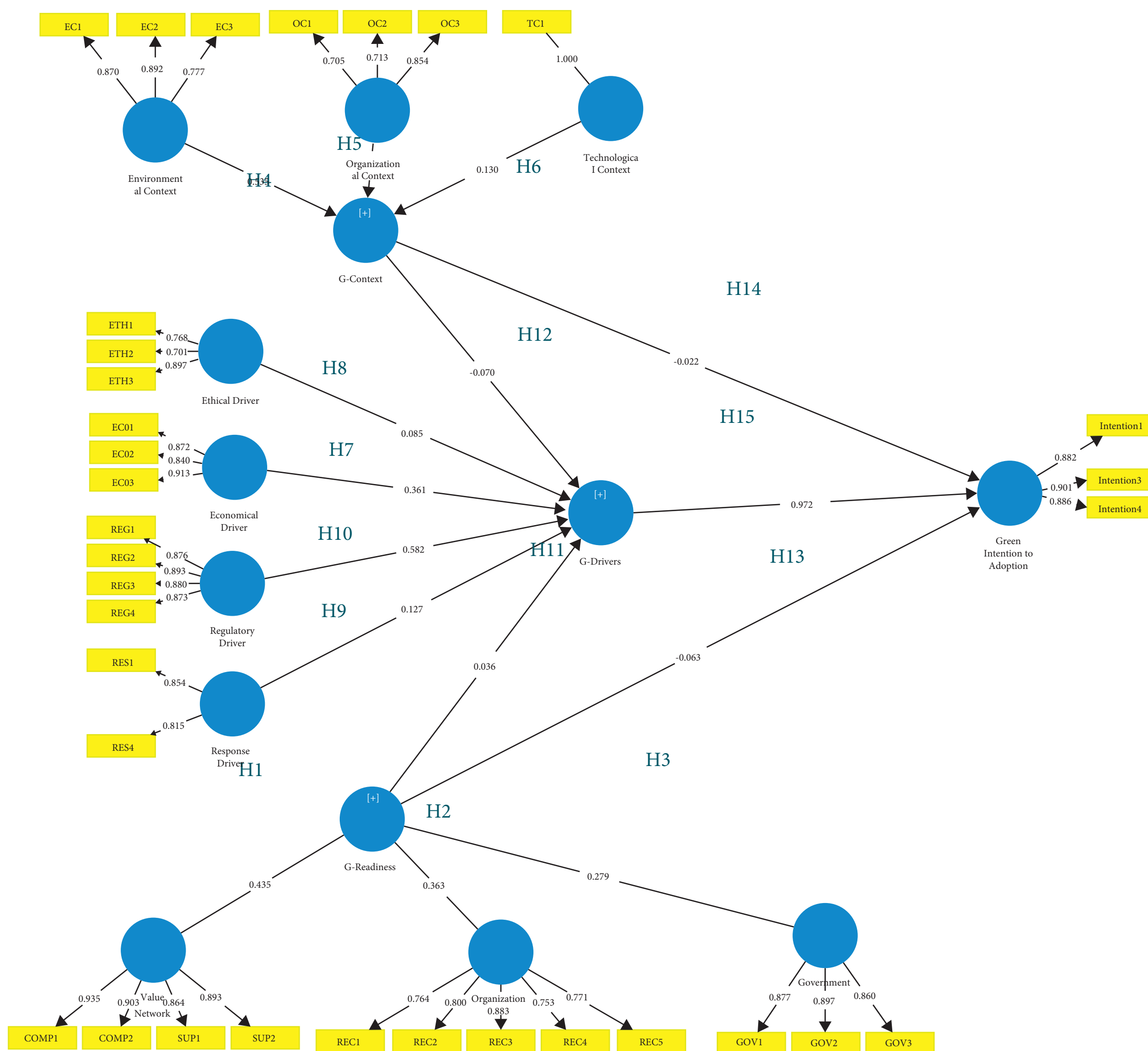

Figure 2: PLS outer loads.

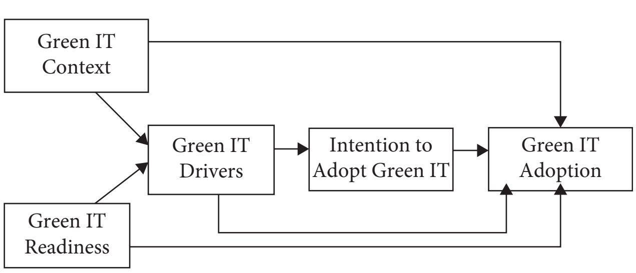

Figure 3: Final model.

Table 4: CV communality.

Coefficient	SSO	SSE	Q^2
G-context	679	287.515	0.577
G-drivers	970	483.788	0.501
G- readiness	1164	498.506	0.572
Green intention to adoption	291	112.205	0.614

the shared values of the software-calculated variables in the fitness evaluation of the model. GOF was found to be 0.9, confirming the fitness of the model (Table 4).

5. Managerial Insight

The important recommendation as managerial insight of the research is as follows:

(i) The effect of green IT context on green IT adoption is significant, therefore, paying attention to the fact that green IT context will be able to create value for Iranian CIOs. Also, organizations fully understood the effect of green IT context in the green IT adoption by using green IT drivers as an intermediate factor.

(ii) The effect of green IT readiness on green IT adoption is significant. Therefore, paying attention to green IT readiness will be able to create value for Iranian CIOs. Also, organization has fully understood the effect of green IT readiness in the green IT adoption by using green IT drivers as an intermediate factor.

(iii) The effect of green IT drivers on green IT adoption is significant. Therefore, paying attention to green IT drivers will be able to create value for Iranian CIOs. Also, organizations have fully understood the effect of green IT drivers in the green IT adoption as intermediate.

(iv) The effect of green intention on green IT adoption is significant. Therefore, paying attention to green intention will be able to create value for Iranian CIOs. Also, organizations fully understood the effect of green intention in the green IT adoption as only intermediate.

6. Conclusion

Organizations are under continuous pressure to develop environmental sustainability improvement innovations. The successful tackling of environmental problems has been argued to possibly bring new competition opportunities and allow for adding value to core corporate practices. GIT is a crucial field in IT management. It is expected that organizations deal with ICT sustainability. IT sustainability has recently been of great interest to works on the environmental sustainability improvement of organizations.

The present study aimed to extract factors influencing GIT adoption through the views of CIOs. Three hypotheses were proposed. The findings demonstrated the statistical significance of the hypotheses. The relationships of the GIT context, GIT drivers, and GIT readiness on GIT adoption were explored. It was observed that the GIT context and GIT readiness had positive effects on the intention to adopt GIT solely under the presence of GIT drivers. The present work utilized GIT drivers as a mediating factor. The proposed hypotheses were confirmed at 0.99% of reliability. Therefore, the main results of effect between factors are as follows:

(i) Path1: economical –> G-drivers = confirmed

(ii) Path2: environmental –> G-context = confirmed

(iii) Path 3: ethical driver –> G-drivers = confirmed

(iv) Path 4: G-context –> G-drivers = confirmed

(v) Path 5: G-context –> green intention to adoption = rejected

(vi) Path 6: G-drivers –> green intention to adoption = confirmed

(vii) Path 7: G-readiness –> G-drivers = confirmed

(viii) Path 8: G-readiness –> green intention to adoption = rejected

(ix) Path 9: government –> G-readiness = confirmed

(x) Path 10: organizational –> G-readiness = confirmed

(xi) Path 11: organizational context –> G-context = confirmed

(xii) Path 12: regulatory driver –> G-drivers = confirmed

(xiii) Path 13: response driver –> G-drivers = confirmed

(xiv) Path 14: technological context –> G-context = confirmed

(xv) Path 15: value network –> G-readiness = confirmed

Considering that the determination of coefficients and the analysis of relationships between factors directly depend on the opinion of experts and if the opinion of expert's changes, the results will also change; this can be mentioned as the most important limitation of the research.

This study makes suggestions for saving energy and improving organizational GIT performance. The general and specialized training of managers is helpful in long-term organizational performance improvement. Incentives could be provided in the form of discounts and wage bonuses. The modification of organizational structure to support GIT schemes is a short-term measure for organizational performance improvement. Finally, the alternation of IT operations (e.g., configuration management and asset systems) would be a green measure.

Data Availability

The data that support the findings of this study can be obtained from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Minimizing the Machine Processing Time in a Flow Shop Scheduling Problem under Piecewise Quadratic Fuzzy Numbers

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The piecewise quadratic fuzzy number (PQFN) can signify uncertain information that exists in scientific, technological, and engineering fields. Hence, it is a useful tool for describing information in scheduling problems. This study examines structured n-job flow shop scheduling with fuzzy piecewise quadratic processing times and three machines. Close interval approximation of PQFNs is also offered as one of the most effective approximate intervals. Furthermore, the leasing cost of equipment is minimized with the use of a fuzzy style and an inventive algorithm. To demonstrate how the proposed framework can be used, a numerical illustration is provided.

1. Introduction

Scheduling dilemma is concerned with determining the optimal or nearly optimal schedule under certain limitations. Numerous methods have been proposed by several researchers to solve this problem. Scheduling to achieve a specific goal requires a variety of activities by spending time and budget. Flow shop is the most studied production setting in the literature on scheduling. In [1], one of the earliest results in flow shop scheduling is an algorithm for minimizing the completion time of all activities in a two or three-machine shop. Gupta [2] suggested a method for determining the best time to schedule a flow shop scheduling problem (FSSP) with a certain structure.

The method [2] has important considerations and developed by several scholars; see [3–7]. Narian and Bagga [9] investigated the problem of obtaining a sequence that provides the lowest possible cost of renting while minimizing the time spent. Schulz et al. [10] explored a mixture FSSP with varying discrete production speed levels. An upgraded multi-objective algorithm was used by Gheisarihe et al. [11] to solve the flexible FSSP with sequence-based transportation time, a probable network, and setup time.

In the real-world applied scientific problems, due to the complexity of different systems and the inaccuracy of data, classical methods cannot take into account inaccuracies in discussions. Therefore, using tools such as fuzzy perspective [12] can be helpful in managing this important task (see also [13, 14]).

The theory of fuzzy sets and its applications in optimization were proposed by Zimmermann [15]. Kaufmann and Gupta [16] studied several fuzzy mathematical models with their applications to engineering and management sciences.

By using triangular fuzzy sets to describe work processing times, Petrovic and Song [17] studied the task sequence problem in a two-machine flow shop. Multi-product parallel multi-stage cell manufacturing organizations can apply Saracoglu and Suer's methodology [18] to create items on time. They employed this methodology in the case study of a shoe manufacturing plant to produce products on time. Pang et al. [19] presented the FSSP and hybrid flow shop scheduling with the intention of determining the optimal scheduling approach for manufacturing facilities. Shao et al. [20] examined a distributed fuzzy blocking FSSP with processing times represented by fuzzy numbers, with the goal of minimizing the fuzzy makespan across all components. Recently, some papers are introduced to deal with real-world problems in fuzzy environments and their extensions (see [21–26]).

This study aims to investigate a particular *n-job* of scheduling with piecewise quadratic fuzzy number (PQFN). Given the total time elapsed, in which processing times are shown in PQFN, an innovative approach to sequencing tasks is proposed, which minimizes the cost of renting machines.

1.1. Research Gap and Motivation. The following points may lead to motivation of the proposed study.

(1) The piecewise quadratic fuzzy number (PQFN) introduced by Jain [27] is an extended concept of fuzzy set.

(2) In real-world scenarios, distinct parameters are further classified into disjoint sets having sub-parametric values. It presents the optimal selection with the help of suitable parameters. In decision making, the jury may endure some sort of tendency and proclivity while paying no attention to such parametric categorization during the decision.

(3) Inspired from the above literature, new notions of PQFN are conceptualized along with some elementary essential properties and generalized typical results. Moreover, decision-making algorithmic approaches are proposed.

1.2. Main Contributions and Advantages. The following are the main contributions of this proposed study:

(1) The existing relevant models are made adequate with the consideration of multi-argument approximate function through the development of the fuzzy set theory.

(2) The scenario where parameters are further partitioned into sub-parametric values in the form of sets is tackled by using PQFNs.

(3) Some fundamentals like elementary properties and arithmetic operations of PQFNs are characterized.

(4) Decision-making applications are discussed based on the proposal of PQFNS arithmetic operations.

(5) The results of the proposed similarity are compared with relevant existing models.

(6) The proposed structure is compared with relevant models under suitable evaluating indicators.

(7) The advantageous aspects of the proposed structure are discussed. The generalization of proposed structure is presented.

1.3. Paper Organization. This paper is organized as follows. The next section introduces the preliminaries of PQFNs and some notations. A three-stage FSSP model is provided in Section 3. Section 4 provides an efficient method for determining the sequence of jobs that minimizes the cost of equipment rental. Section 5 gives a numerical example for illustration. Section 6 introduces a comparative study with the existing methods. Finally, the conclusions are drawn in Section 7.

2. Prerequisites

Here, we study some preliminaries that we need for the main sections (for more details, see [27]).

Definition 1. A PQFN is denoted by $\widetilde{W}_{PQ} = (w_1, w_2, w_3, w_4, w_5)$, where $w_1 \leq w_2 \leq w_3 \leq w_4 \leq w_5$ are real numbers, and its membership function $\mu_{\widetilde{W}_{PQ}}$ is given by

$$\mu_{\widetilde{W}_{PQ}} = \begin{cases} 0, & x < w_1; \\ \frac{1}{2}\frac{1}{(w_2 - w_1)^2}(x - w_1)^2, & w_1 \leq x \leq w_2; \\ \frac{1}{2}\frac{1}{(w_3 - w_2)^2}(x - w_2)^2 + 1, & w_2 \leq x \leq w_3; \\ \frac{1}{2}\frac{1}{(w_4 - w_3)^2}(x - w_3)^2 + 1, & w_3 \leq x \leq w_4; \\ \frac{1}{2}\frac{1}{(w_5 - w_4)^2}(x - w_4)^2, & w_4 \leq x \leq w_5; \\ 0, & x > w_5. \end{cases} \quad (1)$$

Figure 1 shows the graphical representation of a PQFN.

Definition 2. Let $\widetilde{U}_{PQ} = (u_1, u_2, u_3, u_4, u_5)$ and $\widetilde{V}_{PQ} = (v_1, v_2, v_3, v_4, v_5)$ be two PQFNs. Then, we have

(i) Addition: $\widetilde{U}_{PQ}(+)\widetilde{V}_{PQ} = (u_1 + v_1, u_2 + v_2, u_3 + v_3, u_4 + v_4, u_5 + v_5)$.

(ii) Subtraction: $\widetilde{U}_{PQ}(-)\widetilde{V}_{PQ} = (u_1 - v_5, u_2 - v_4, u_3 - v_3, u_4 - v_2, u_5 - v_1)$.

(iii) Scalar multiplication: $k\widetilde{U}_{PQ} = \begin{cases} (ku_1, ku_2, ku_3, ku_4, ku_5), & k > 0, \\ (ku_5, ku_4, ku_3, ku_2, ku_1), & k < 0. \end{cases}$

Definition 3. For the close interval approximation (CIA) of PQFN of $[U] = [U_\alpha^-, U_\alpha^+]$, we call $\widehat{U} = U_\alpha^- + U_\alpha^+/2$ as the associated real number of $[U]$.

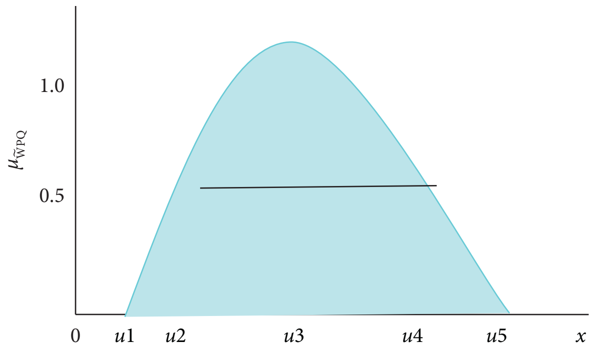

FIGURE 1: Graphical representation of a piecewise quadratic fuzzy number (PQFN).

Definition 4. For $[U] = [U_\alpha^-, U_\alpha^+]$ and $[V] = [V_\alpha^-, V_\alpha^+]$, we have the following properties:

(1) Addition: $[U](+)[V] = [U_\alpha^- + Vb_\alpha^-, U_\alpha^+ + V_\alpha^+]$.

(2) Subtraction: $[U](-)[V] = [U_\alpha^- - V_\alpha^+, U_\alpha^+ - V_\alpha^-]$.

(3) Scalar multiplication:$k[U] = \begin{cases} [kU_\alpha^-, kU_\alpha^+], & k > 0 \\ [kU_\alpha^+, kU_\alpha^-], & k < 0 \end{cases}$.

(4) Multiplication: $[U](\times)[V]$, $[U_\alpha^+ V_\alpha^- + U_\alpha^- V_\alpha^+/2, U_\alpha^- Vb_\alpha^- + U_\alpha^+ V_\alpha^+/2]$.

(5) Division: $[U](\div)[V]$, $\begin{cases} [2(U_\alpha^-/V_\alpha^- + V_\alpha^+), \\ 2(U_\alpha^+/V_\alpha^- + V_\alpha^+)], & [V] > 0, V_\alpha^- + V_\alpha^+ \neq 0 \\ [2(U_\alpha^+/V_\alpha^- + V_\alpha^+), \\ 2(U_\alpha^-/V_\alpha^- + V_\alpha^+)], & [V] < 0, V_\alpha^- + V_\alpha^+ \neq 0 \end{cases}$.

(6) The order relations:

(i) $[U](\underset{\sim}{\leq})[V]$ if $U_\alpha^- \leq V_\alpha^-$ and $U_\alpha^+ \leq V_\alpha^+$ or $U_\alpha^- + U_\alpha^+ \leq V_\alpha^- + V_\alpha^+$.

(ii) $[U]$ is preferred to $[V]$ if and only if $U_\alpha^- \geq V_\alpha^-, U_\alpha^+ \geq V_\alpha^+$.

2.1. Symbolization. Table 1 shows the symbols of our work.

3. Methodology

Before we discuss the issue formulation, let us define the rental cost.

3.1. Cost of Renting. The machines are rented out if needed and returned if they are no longer needed. For example, the first machine is rented at the beginning of the work process, the second machine is rented when the first work is completed in the first machine, and so on.

Suppose that some tasks $i, i = \overline{1,n}$ under the definite rental policy L are managed on three machines $M_j, j = 1, 2, 3$. Let $\widetilde{a}_{ij}^{PQ}$ be the PQFPT of i-th task on j-th machine (see Table 2). Let $S_{ij}, i = \overline{1,n}; j = 1, 2, 3$. Determine the related processing times with crisp number on devices M_1, M_2, and M_3 in such a way that either $\widehat{a}_{j2} \leq \widehat{a}_{i1}$ or $\widehat{a}_{j2} \leq \widehat{a}_{i3}; \forall i, j$. Our objective is to determine $\{S_k\}$ of the tasks that minimizes the cost of renting the equipment.

The problem may be expressed mathematically as follows:

$$\min \widetilde{R}^{PQ}(S_k) = \sum_{i=1}^{n} \widetilde{a}_{i1}^{PQ} \times C_1 + \widetilde{U}_2^{PQ}(S_k) \times C_2 + \widetilde{U}_3^{PQ}(S_k) \times C_3 \text{ Subject to rental policy L}. \quad (2)$$

Using the CIA of PQFN, model (10) may be reformulated as follows:

$$\min[R_\alpha^-(S_k), R_\alpha^+((S_k)] = \sum_{i=1}^{n} [(a_{i1})_\alpha^-, (a_{i1})_\alpha^+] \times C_1 + [U_{2\alpha}^-(S_k), U_{2\alpha}^+(S_k)] \times C_2 + [U_{3\alpha}^-(S_k), U_{3\alpha}^+(S_k)] \times C_3 \text{ Subject to rental policy L}. \quad (3)$$

Table 2 may be recreated in CIA of PQFN format as shown in Tables 3 and 4.

4. Proposed Algorithm

In this part, we show our strategy for minimizing the time and, consequently, the cost of renting a three-stage FSSP with PQF-based processing time while ignoring the makespan.

Step 1. Find the associated ordinary number for all tasks.

Step 2. If $\widehat{a}_{j2} \leq \widehat{a}_{i1}$ or $\widehat{a}_{j2} \leq \widehat{a}_{i3}; \forall i, j$, i.e., $\max\{\widehat{a}_{i1}\} \geq \min\{\widehat{a}_{j2}\}$ or $\max\{\widehat{a}_{i3}\} \geq \min\{\widehat{a}_{j2}\}; \forall i, j$, go to next step; otherwise, break.

Table 1: List of symbols.

Abbreviations	Descriptions
S	Arrangement of jobs, $i = \overline{1, n}$
S_k	Sequence obtained through the method [1], $k = 1, 2, \ldots, n$
M_h	Machine $h, h = 1, 2, 3$
M	Minimum makespan
$\widetilde{a}_{lh}^{P}$	PQF processing time (PQFPT) for the l-th task on $M_h, h = 1, 2, 3$
$[a_{ij}^{PQ}]$	Close interval estimate of the PQFPT of the i-th task in sequence S_k running on M_j
$t_{ij}(S_k)$	Time of i-th task for S_k on M_j
$U_j(S_k)$	Consumption time for M_j that is necessary for S_k
$CT(S_k)$	Whole completion time
$I_{ij}(S_k)$	Idle time
$\widehat{a}_{ij}$	Corresponding normal time of the i-th task on M_j
$R(S_k)$	Whole rental payment
C	Cost of renting

Table 2: Description of the problem with the PQFN matrix.

Tasks	M_1	M_2	M_3
i	$\widetilde{a}_{i1}^{PQ}$	$\widetilde{a}_{i2}^{PQ}$	$\widetilde{a}_{i3}^{PQ}$
1	$\widetilde{a}_{11}^{PQ}$	$\widetilde{a}_{12}^{PQ}$	$\widetilde{a}_{13}^{PQ}$
2	$\widetilde{a}_{21}^{PQ}$	$\widetilde{a}_{22}^{PQ}$	$\widetilde{a}_{23}^{PQ}$
...	...	...	...
n	$\widetilde{a}_{n1}^{PQ}$	$\widetilde{a}_{n2}^{PQ}$	$\widetilde{a}_{n3}^{PQ}$

Table 3: The problem with CIA matrix.

Tasks	M_1	M_2	M_3
i	$[(a_{i1})_\alpha^-, (a_{i1})_\alpha^+]$	$[(a_{i2})_\alpha^-, (a_{i2})_\alpha^+]$	$[(a_{i3})_\alpha^-, (a_{i3})_\alpha^+]$
1	$[(a_{11})_\alpha^-, (a_{11})_\alpha^+])$	$[(a_{12})_\alpha^-, (a_{12})_\alpha^+]$	$[(a_{13})_\alpha^-, (a_{13})_\alpha^+]$
2	$[(a_{21})_\alpha^-, (a_{21})_\alpha^+]$	$[(a_{22})_\alpha^-, (a_{22})_\alpha^+]$	$[(a_{23})_\alpha^-, (a_{23})_\alpha^+]$
...	...	...	...
n	$[(a_{n1})_\alpha^-, (a_{n1})_\alpha^+]$	$[(a_{n2})_\alpha^-, (a_{n2})_\alpha^+]$	$[(a_{n3})_\alpha^-, (a_{n3})_\alpha^+]$

Table 4: The problem with the corresponding crisp matrix form.

Tasks	M_1	M_2	M_3
i	$(a_{i1})_\alpha^- + (a_{i1})_\alpha^+/2$	$(a_{i2})_\alpha^- + (a_{i2})_\alpha^+/2$	$(a_{i3})_\alpha^- + (a_{i3})_\alpha^+/2$
1	$(a_{11})_\alpha^- + (a_{11})_\alpha^+/2$	$(a_{12})_\alpha^- + (a_{12})_\alpha^+/2$	$(a_{13})_\alpha^- + (a_{13})_\alpha^+/2$
2	$(a_{21})_\alpha^- + (a_{21})_\alpha^+/2$	$(a_{22})_\alpha^- + (a_{22})_\alpha^+/2$	$(a_{23})_\alpha^- + (a_{23})_\alpha^+/2$
...	...	...	...
n	$(a_{n1})_\alpha^- + (a_{n1})_\alpha^+/2$	$(a_{n2})_\alpha^- + (a_{n2})_\alpha^+/2$	$(a_{n3})_\alpha^- + (a_{n3})_\alpha^+/2$

Step 3. Define dummy machines H_1 and H_2, and their processing times H_1^i and H_2^i are as follows: $H_1^i = \widehat{a}_{i1} + \widehat{a}_{i2}, H_2^i = \widehat{a}_{i2} + \widehat{a}_{i3}; \forall i$.

Step 4. Use the existing algorithm [1] on H_i and get S_1.

Step 5. Put the 2nd,..., n^{th} tasks of the S_1 in the first position and all other tasks of S_1 in the same order.

Step 6. For all possible sequences $S_k, k = \overline{1, n}$, calculate: $\widehat{R}(S_k) = \sum_{i=1}^{n} \widehat{a}_{ij} \times C_1 + \widehat{U}_2(S_k) \times C_2 + \widehat{U}_3(S_k) \times C_3$.

Step 7. Set $\min\{\widehat{R}(S_k)\}, k = \overline{1, n}$ as the optimal solution.

5. Numerical Example

Consider Table 5 as the problem. Now, we solve this problem by our model.

At first, in Tables 6 and 7, we compute the related interval and crisp numbers for each PQFPT.

Then, using Step 3 of our algorithm, the processing times can be computed as shown in Table 8.

Using procedure [1], S_1:2-4-5-1-3.

The subsequent viable sequences correspond to the minimal rental cost: S_2: $4-2-5-1-3$; S_3: $1-2-4-5-3$; S_4: $3-2-4-5-1$.

Tables 9 and 10 illustrate the in-out flow for the sequence S_1 in the PQFNs and CIA forms.

For S_1, we get the following.

The completion time for S_1 is $\widetilde{CT}^{PQ}(S_1) = (40, 49, 56, 62, 76)$, $[CT(S_1)] = [49, 62]$, and $\widehat{CT}(S_1) = 55.5$.

The consumption time for machine M_2 is $\widetilde{U}_2^{PQ}(S_1) = (11, 23, 30, 38, 53)$, $[U_2(S_1)] = [23, 38]$, and $\widehat{U}_2(S_1) = 30.5$.

The consumption time for machine M_3 is $\widetilde{U}_3^{PQ}(S_1) = (14, 28, 37, 45, 61)$, $[U_3(S_1)] = [28, 45]$, and $\widehat{U}_3(S_1) = 36.5$.

$$\begin{aligned}\widetilde{R}^{PQ}(S_1) &= \sum_{i=1}^{5} \widetilde{a}_{i1} \times C_1 + U_2(S_1) \times C_2 + U_3(S_1) \times C_3 \\ &= (572, 726, 831, 935, 1145), [R(S_1)] \\ &= [726, 935] \text{ and } \widehat{R}(S_1) = 830.5.\end{aligned} \tag{4}$$

Similarly, we have the following.

For S_2:

$$\begin{aligned}&\widetilde{CT}^{PQ}(S_2) = (37, 47, 54, 61, 73), \\ &[CT(S_2)] = [47, 61], \text{and } \widehat{CT}(S_2) = 54,\end{aligned} \tag{5}$$

$$\begin{aligned}\widetilde{U}_2^{PQ}(S_2) &= (12, 23, 30, 38, 52), [U_2(S_2)] \\ &= [23, 38], \text{and } \widehat{U}_2(S_2) = 30.5,\end{aligned} \tag{6}$$

Table 5: PQFN processing times for machines.

Tasks	M_1	M_2	M_3
i	$\tilde{a}_{i1}^{PQ}$	$\tilde{a}_{i2}^{PQ}$	$\tilde{a}_{i3}^{PQ}$
1	(6,7,8,9,10)	(5,6,7,8,10)	(2,3,4,5,7)
2	(11,12,13,14,17)	(4,5,6,7,9)	(3,4,5,6,8)
3	(7,8,10,12,14)	(3,4,5,6,9)	(5,6,7,8,9)
4	(9,10,11,12,14)	(3,5,6,7,9)	(10,11,12,13,15)
5	(7,9,10,11,13)	(2,5,6,8,10)	(5,8,9,10,11)

Table 6: PQFN processing times with interval format.

Tasks	M_1	M_2	M_3
i	$[a_{i1}^{PQ}]$	$[a_{i2}^{PQ}]$	$[a_{i3}^{PQ}]$
1	[7,9]	[6,8]	[3,5]
2	[12,14]	[5,7]	[4,6]
3	[8,12]	[4,6]	[6,8]
4	[10,12]	[5,7]	[11,13]
5	[9,11]	[5,8]	[8,10]

Table 7: PQFN processing times with crisp format.

Tasks	M_1	M_2	M_3
i	$\hat{a}_{i1}$	$\hat{a}_{i2}$	$\hat{a}_{i3}$
1	8	7	4
2	13	6	5
3	10	5	7
4	11	6	12
5	10	6.5	9

Table 8: The related crisp numbers of the processing times.

Tasks	H_1	H_2
1	15	11
2	19	11
3	15	12
4	17	18
5	16.5	15.5

Table 9: The in-out flow for S_1 in the PQFNs.

Tasks	M_1	M_2	M_3
i	In- out	In- out	In- out
2	(11,12,13,14,17)	(15,17,19,21,26)	(18,21,24,27,34)
4	(19,22,24,26,31)	(18,22,25,28,35)	(28,32,36,39,49)
5	(26,31,34,37,44)	(20,27,31,36,45)	(33,40,45,49,60)
1	(32,38,42,46,54)	(25,33,38,44,55)	(35,43,49,54,67)
3	(39,46,52,58,68)	(28,37,43,50,64)	(40,49,56,62,76)

$$\tilde{U}_3^{PQ}(S_2) = (14, 28, 37, 45, 61), [U_3(S_2)] = [28, 45], \text{and } \hat{U}_2(S_2) = 36.5, \tag{7}$$

Table 10: The in-out flow for S_1 in CIA.

Jobs	Machine M_1	Machine M_2	Machine M_3
2	[12,14]	[17,21]	[21,27]
4	[22,26]	[22,28]	[32,39]
5	[31,37]	[27,36]	[40,49]
1	[38,46]	[33,44]	[43,54]
3	[46,58]	[37,50]	[49,62]

$$\tilde{R}^{PQ}(S_2) = \sum_{i=1}^{5} \tilde{a}_{i1}^{PQ} \times C_1 + \tilde{U}_2^{PQ}(S_2) \times C_2 + \tilde{U}_3^{PQ}(S_2) \times C_3 = (582, 718, 769, 927, 1131), [R(S_2)] = [718, 927], \text{and } \hat{R}(S_1) = 822.5. \tag{8}$$

For S_3, we have

$$\widetilde{CT}^{PQ}(S_3) = (36, 45, 52, 59, 70), [CT(S_3)] = [45, 59], \text{and } \widehat{CT}(S_3) = 52, \tag{9}$$

$$\tilde{U}_2^{PQ}(S_3) = (13, 23, 30, 38, 49), [U_2(S_3)] = [23, 38], \text{and } \hat{U}_2(S_3) = 30.5, \tag{10}$$

$$\tilde{U}_3^{PQ}(S_3) = (16, 28, 37, 46, 59), [U_3(S_3)] = [28, 46], \text{and } \hat{U}_2(S_3) = 37, \tag{11}$$

$$\tilde{R}^{PQ}(S_3) = \sum_{i=1}^{5} \tilde{a}_{i1}^{PQ} \times C_1 + \tilde{U}_2^{PQ}(S_3) \times C_2 + \tilde{U}_3^{PQ}(S_3) \times C_3 = (562, 686, 791, 896, 1075), [R(S_3)] = [686, 896], \text{and } \hat{R}(S_3) = 791. \tag{12}$$

For S_4, we have

$$\widetilde{CT}^{PQ}(S_4) = (35, 44, 52, 60, 73), [CT(S_4)] = [44, 60], \text{and } \widehat{CT}(S_4) = 52, \tag{13}$$

$$\tilde{U}_2^{PQ}(S_4) = (10, 11, 30, 40, 54), [U_2(S_4)] = [11, 40], \text{and } \hat{U}_2(S_4) = 25.5, \tag{14}$$

$$\tilde{U}_3^{PQ}(S_4) = (12, 26, 37, 48, 63), [U_3(S_4)] = [26, 48], \text{and } \hat{U}_2(S_4) = 37, \tag{15}$$

$$\tilde{R}^{PQ}(S_4) = \sum_{i=1}^{5} \tilde{a}_{i1}^{PQ} \times C_1 + \tilde{U}_2^{PQ}(S_4) \times C_2 + \tilde{U}_3^{PQ}(S_4) \times C_3 = (560, 672, 823, 956, 1161), [R(S_4)] = [672, 956], \text{and } \hat{R}(S_4) = 814. \tag{16}$$

Table 11: Comparison of different researchers' contributions.

Author	Processing time	Piecewise quadratic fuzzy numbers	Close approximate interval	Minimum rental cost
Ruiz et al. [28]	↓	↓	↓	↑
Liang et al. [29]	↑	↓	↓	↑
Sanchez-Herrera et al. [30]	↑	↓	↓	↑
Our proposed approach	↑	↑	↑	↑

For S_5, we have

$$\widehat{R}(S_5) = 2066.6257. \quad (17)$$

Thus,

$$\widetilde{R}^{PQ}(S_3) = \sum_{i=1}^{5} \widetilde{a}_{i1}^{PQ} \times C_1 + \widetilde{U}_2^{PQ}(S_3) \times C_2 + \widetilde{U}_3^{PQ}(S_3) \times C_3 = (562, 686, 791, 896, 1075), \quad (18)$$

$$[R(S_3)] = [686, 896]. \quad (19)$$

Therefore, S_3: $1-2-4-5-3$ is the optimal sequence subject to the minimum rental cost, and $\widehat{R}(S_3) = 791$ is the minimum rental cost irrespective of the total time passed.

6. Comparative Study

In this section, the proposed approach is compared with some existing studies to illustrate the advantages of the proposed approach. The results for this analysis are summarized in Table 11. The symbol "↓" or "↑" shown in the table represents whether the associated feature satisfies or not.

7. Conclusions and Future Works

In this paper, the problem of minimizing the cost of renting machines for flow shop scheduling with a specific structure is investigated. An innovative approach to solve it is then proposed in which the processing times are fragmented as piecewise quadratic fuzzy numbers. The result shows that the proposed method has its advantage in flexible decision making corresponding to favorite priorities of alternatives. This study may be extended to additional fuzzy-like structures, such as interval-valued fuzzy set, Pythagorean fuzzy set, spherical fuzzy set, intuitionistic fuzzy set, picture fuzzy set, neutrosophic set, and so on, in future work.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A Mixed Integer Programming Optimization of Blood Plasma Supply Chain in the Uncertainty Conditions during COVID-19: A Real Case in Iran

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Blood and its products, like plasma, are among the most sensitive products for the sake of transportation and storage. Special storage conditions, short shelf life, and lack of particular demand for blood products are among the most significant challenges to managing it. In this respect, it is necessary to implement the problem of supply chain network design in uncertain conditions to find a proper solution for the management of blood products. In this study, a multilevel supply chain is designed to supply plasma in the COVID-19 pandemic. First, the blood is sent to blood donation centers and then to the laboratory. Moreover, after that, it is sent to hospitals. To optimize the transfer rate at each level of the supply chain, a mathematical model is proposed to reduce total costs. Also, the fuzzy programming approach is used to deal with uncertainty in the parameters of the mathematical model. The results of model optimization show that this mathematical model has the required efficiency in finding optimal solutions for the distribution of blood products. According to the obtained results, value objective function in certain and uncertain values is determined. According to the results, the objective certain value is lower than the uncertain value. Uncertain value calculated is of three dimensions. According to this, the categorized objective value increased when the dimension is equal to 0.5. Finally, it shows that when demand increases, more blood and plasma need to be collected to meet the demand, which increases operating and health testing costs and ultimately increases total system costs.

1. Introduction

In previous years, the design network blood chain has been one of the most attractive areas in the field of health care systems. What differentiates this chain from other supply chains is that, unlike business supply chains, that are based on profit, it is based on service. Additionally, deficiency of blood products could significantly lead to death [1]. Supply of healthy and adequate blood and its management has been of particular importance for the salvation of humanity; therefore, timely blood collection and distribution is considered as supply chain management for which detailed planning is required because the slightest disruption in the management of the blood supply chain and its products will cause irreparable damage to the people [2]. Generally, blood products such as red blood cells, platelets, and plasma have different special storage procedures and have different shelf life. A blood supply chain includes various activities such as collecting, producing, storing, and distributing blood and blood products. The main activities of the blood supply chain start from the donors and end with the recipients, which is accompanied by uncertainties along the chain such as supply and demand. Uncertainty in supply chain issues plays a fundamental role in economic performance. Therefore, under such uncertainties, in order to fairly regulate supply and demand in the blood supply chain, a suitable network for adequate blood supply and blood products must be designed [3]. To this objective, new approaches should be provided to make the right decision in order to use resources properly. In addition, it provided proper planning for blood collection and transfusion for better management in emergencies such as pandemics, emergencies, and earthquakes [4]. Therefore, the right decision in blood transfusion is to replace blood with other blood groups. The ideal situation for a blood transfusion is for the donor's blood type to be the same as the recipient's. However, this is not always possible. When there is no recipient blood type, compatible and alternative blood types should be used [5]. The COVID-19 outbreak began in late 2019 in Wuhan, China, and spread worldwide by 2020 [6]. Given that the loss of life was initially greater than the impact of COVID-19, only quarantine and social distancing was the only way to deal with the pandemic because the research of COVID-19 vaccine was not completed and was not widely available to all people in the world [7]. The pandemic COVID-19, caused by acute respiratory inflammation, is causing major disruptions to health care at a global scale at all levels. A key activity for blood transfusion facilities is to monitor supply and demand so that enough blood reserves are saved to support ongoing critical requirements [8]. Plasma taken from the blood of improved patients, which contains COVID-19 antibodies, can be beneficial for improving the performance of new patients. Therefore, incorporating donors recovered from COVID-19 can play an important role in improving the function of the blood supply chain.

According to the above mention, basic goals of the research are as follows:

(O1) Create a blood network to consider the value of receiving blood plasma during the COVID-19 epidemic

(O2) Minimize the collected plasma blood cost in the COVID-19 pandemic

(O3) Apply deterministic mathematical programming to measure the behavior of the model presented in a real-world case study

Therefore, the main question of the research is as follows:

(Q1) How can the amount of blood plasma collected be calculated at the lowest cost in a COVID-19 pandemic?

The structure of the paper is categorized in such a way that the literature review is provided in Section 2. The mathematical model is presented in Section 3. Numerical results are presented in Section 4, and finally, conclusion and future directions are explained in Section 5.

2. Literature Review

There have been many studies in recent years on the blood supply chain. There are various approaches to blood supply chain modeling, such as simulation models, integer programming, and ideal programming. For the first time, Van Zyl [9] conducted studies in the field of transmission and distribution management of blood products and supply chain of perishable materials. The first mathematical model for managing the inventory of blood products was also proposed by Nahmias [10]. Derikvand et al. [11] suggested a new mathematical model with the aims of minimizing the cost of developing blood collection centers, the cost of deficiency, and the cost of corrupted blood and minimizing the maximum demand met in the affected areas. Ghorashi et al. [12] considered a mathematical planning model with the aims of reducing the cost of organizing permanent and temporary centers, operating cost of blood collection, cost of transporting blood between chain levels, cost of inventory maintenance, maximizing reliability of created path from permanent blood centers to medical center, and minimizing blood transportation times between chain levels in disaster conditions. Han Shih and Rajendran [13] designed a mathematical model for designing a blood supply chain network with the aim of reducing the cost of deficiency, the cost of transporting blood between chain levels, the cost of corrupted blood, the operating cost of collecting blood, and the cost of maintaining inventory in conditions of uncertainty. Kaya and Ozkok [14] provided a mathematical planning model for designing a blood supply chain network with the aim of minimizing the cost of establishing permanent centers, the cost of transporting blood between chain levels, and the cost of maintaining inventory. Adrang et al. [15] provided a robust location-routing mathematical model for heath care centers. The objectives of this mathematical model are to reduce relief time and the costs of the entire supply chain. The total costs considered are derived from the sum of the local costs and the costs of covering the path with the transporter. In this research, two types of ambulance vehicles and helicopters have been considered. Tirkolaee et al. [16] provided a robust mathematical allocation and scheduling model for mishap amendment. For this purpose, a robust MILP model is designed to achieve the objectives of the problem. Asadpour et al. [2] proposed a mathematical model with the goal of minimizing the environmental effects of blood collection between chain levels and minimizing the cost of implementation blood centers, the cost of maintaining inventory, and the cost of transporting blood between chain levels. Considering the need for blood and its products, whole blood and COVID-19 plasma were used simultaneously in this research. This research is also the first study in Shiraz metropolis. Rezaei et al. [17] in their study proposed a mathematical model for routing blood-carrying vehicles in critical situations by considering adaptive blood supply through alternative blood groups. In this article, two types of vehicles, buses, and helicopters are considered. Helicopters are used to prevent unnecessary travel of blood buses from the blood supply station to the crisis-stricken city. The proposed model considers two objectives. First, maximize the blood collected in blood donation centers. Second, minimize the arrival time of blood-sucking vehicles to the crisis-stricken city. Jahangiri et al. [6] presented a new approach for analysis of the emergency department in the general hospital under COVID-19 condition according to simulation-based optimization. According to the obtained results, effective resource combination was determined using an approximate regression model. Jahangiri et al. [7] presented a hybrid decision framework to ranking key resources for implication of humanitarian supply chain in the emergency department during the COVID-19 pandemic. Arani et al. [18] proposed a mathematical model based on mixed integer programming for a stable blood supply chain. In this study, the issue of routing of blood flow vehicles under conditions of

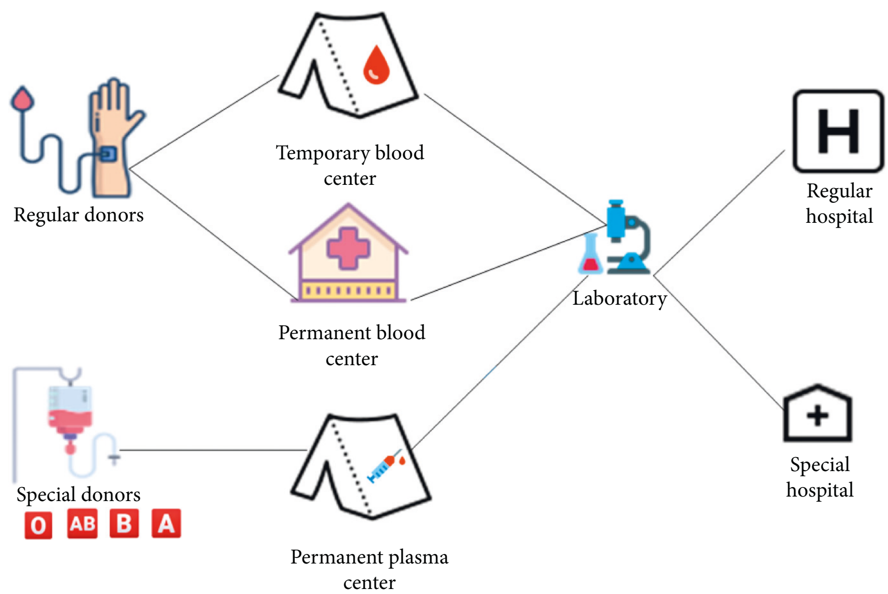

Figure 1: Schematic of blood supply chain of the proposed model.

uncertainty for supply and demand parameters is addressed. In addition, by considering scenarios, a scenario-based optimization model is developed using the proposed model. Goodarzian et al. [19] proposed a mathematical planning model for a sustainable drug supply chain with uncertainty in mind. In this paper, a fuzzy complex LIP model is proposed to deal with the existing uncertainty.

2.1. Research Gap. According to the literature review in the previous section, the main gap of the research is as follows.

The blood supply network is not observed to consider the amount of plasma collected in the COVID-19 pandemic, so that it can minimize the cost of blood plasma collection and also be used in a real system.

3. Research Method

3.1. Problem Statement. In this research, blood supply chain modeling has been performed at four levels. The first level of supply chain includes donors, the second level is blood and plasma collection centers, the third level is health testing center, and the fourth level is demand points. In Figure 1, the schematic of the blood supply chain of the proposed model is shown.

Regular donors donate blood to temporary or permanent centers, and donors who have recovered from COVID-19 donate plasma to permanent centers. Donated blood is transferred from interim centers to continual centers. Then, the blood collected in the permanent centers as well as the blood plasma maintained in the permanent center is transferred to the laboratories, and after confirming the health, they are sent to demand points. The goal of the presented mathematical model is to define optimum decisions about the location of blood centers, blood donation by donors through temporary and permanent centers, and COVID-19 plasma donation by donors who have recovered from this disease through a permanent center and blood and plasma transfer to permanent centers and laboratory and demand points in each time period. The goal function of the presented model is to reduce the fixed costs of establishing the facility, the operating cost of collecting blood and plasma from donors in blood centers, the cost of transportation between supply chain levels, and the cost of blood and plasma health testing. In this model, real-world constraints such as meeting blood and plasma demand in each period, blood and plasma storage capacity, and establishing temporary facilities were considered. Parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are considered uncertain. In the following, the assumptions, sets, parameters, and decision variables and the structure of the mathematical model are described.

3.2. Problem Assumptions. In this paper, mathematical modeling has some assumptions as follows:

(1) Two types of donors are considered: regular donors and those who have recovered from COVID-19
(2) There are two types of demand points for response to whole blood and COVID-19 plasma
(3) Blood collected in the interim and continual centers and plasma collected in the continual center must be taken to a laboratory for blood health testing
(4) Two kinds of blood donation vehicles are considered: interim and continual and a permanent center for COVID-19 plasma
(5) Any donor can donate to blood centers or interim vehicles
(6) The model is intended as a multiperiod model for controlling complex decisions and satisfying different demands

(7) Storage is not possible in temporary centers, and storage can only be done in permanent centers and laboratories

3.3. Notation. In this section, the sets, parameters, and decision variables used in the model are given in Table 1.

3.4. Model Formulation. In this section, mathematical modeling formulation that include objective function and constraint are described.

3.4.1. Objective Function

$$\begin{aligned} \min Z = & \sum_{m'} FR_{m'} XR_{m'} + \sum_{t} \mathrm{FUPR}_t + \sum_{m} \mathrm{FR}_m \mathrm{XR}_m + \sum_{m'}\sum_{k'}\sum_{t} Q''_{m'k't}\widetilde{C_{m'k'}} \\ & + \sum_{j}\sum_{k}\sum_{t} Qjkt\widetilde{C_{jk}} + \sum_{k}\sum_{m}\sum_{t} Q''_{mkt}\widetilde{C_{mk}} + \sum_{j}\sum_{m}\sum_{t} Q'_{mkt}\widetilde{\mathrm{CA}_{jmt}} \\ & + \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\widetilde{\mathrm{CT}_{mlt}} + \sum_{m'}\sum_{l}\sum_{t} Q'''_{m'lt}\widetilde{CD_{m'lt}} + \sum_{l}\sum_{n}\sum_{t} Q''_{lnt}\widetilde{\mathrm{CB}_{lnt}} \\ & + \sum_{l}\sum_{n'}\sum_{t} Q'''_{ln't}\widetilde{CB_{ln't}} + \sum_{m}\sum_{l}\sum_{t} Q'''_{mlt}\widetilde{C_l} + \sum_{m'}\sum_{l}\sum_{t} Q'''_{m'lt}\widetilde{C_l}. \end{aligned} \tag{1}$$

3.4.2. Constraints

$$\sum_{j} \mathrm{YU}_{jkt} + \sum_{m} YR_{mkt} \le 1 \forall k, t, \tag{2}$$

$$Q_{jkt} \le \mathrm{MYU}_{jkt} \forall j, k, t, \tag{3}$$

$$Q''_{mkt} \le \mathrm{MYR}_{mkt} \forall m, k, t, \tag{4}$$

$$Q'''_{m'k't} \le \mathrm{MYR}'_{m'k't} \forall m', k', t, \tag{5}$$

$$\sum_{j_1}\sum_{j} \mathrm{XU}_{j_1 j_t} = Pr_t \forall j1, t, \tag{6}$$

$$\sum_{j} \mathrm{XU}_{j1jt} \le \mathrm{XU}_{j1jt-1} \forall j1, j, \tag{7}$$

$$\mathrm{XR}_m + \sum_{j} \mathrm{XU}_{j1jt} \le 1 \forall m, j, t, \tag{8}$$

$$\sum_{j} Q_{jkt} + \sum_{m} Q''_{mkt} \le d_{kt} \forall k, t, \tag{9}$$

$$\sum_{m'} Q'''_{m'k't} \le d'_{k't} \forall k', t, \tag{10}$$

$$\sum_{j}\sum_{m}\sum_{t} Q''_{jmt} + \sum_{m}\sum_{l}\sum_{t} Q''_{mlt} + \sum_{l}\sum_{n}\sum_{t} Q'''_{lnt} \ge \sum_{n} \widetilde{D_{nt}} \forall t, \tag{11}$$

$$\sum_{m'}\sum_{l}\sum_{t} Q'''_{m'lt} + \sum_{m'}\sum_{n}\sum_{t} Q'''_{m'n't} \ge \sum_{n'} \widetilde{D'_{n't}} \forall t, \tag{12}$$

$$Q''_{mlt} \le \widetilde{capl_{lt}} \forall m, l, t, \tag{13}$$

Table 1: Sets, parameters and variables of the set model.

Set	Description	$\widetilde{capp}_{m't}$	Plasma storage capacity in permanent center m' in period t	
K	Set of regular donors	$\widetilde{capf}_{mt}$	Blood storage capacity in permanent center m in period t	
k'	Set of donors recovered from COVID-19	$\widetilde{C}_l$	Cost of testing each unit of blood and plasma in laboratory l	
M	Blood donation of set of permanent centers	$\widetilde{D}_{nt}$	Amount of blood demands in health care medical center n in period t	
M'	Set of permanent plasma donation centers	$\widetilde{D}_{n't}$	Plasma demand in hospital n' in period t	
J	Set of temporary blood donation centers	d_{kt}	Maximum blood donation from donors k at time t	
T	Set of time periods	$d'_{k't}$	Maximum plasma donation from a donor recovered from COVID-19 K' at time t	
L	Set of laboratories	*Decision variables*	*Description*	*Type of variables*
N	Set of hospitals requesting blood	Q_{jkt}	The amount of blood collected in interim center j from donors k in period t	Continuous
n'	Set of hospitals requesting plasma	Q'_{jmt}	The amount of blood independent of center j to permanent blood center m in period t	Continuous
Parameter	*Description*	Q''_{mkt}	The amount of blood collected in blood center m from donors k in period t	Continuous
$\widetilde{CB}_{lnt}$	Cost of transferring a unit of blood from laboratory l to demand points n in period t	Q'''_{mlt}	The amount of blood independent of permanent blood center m to laboratory center l in period t	Continuous
$\widetilde{CB}_{ln't}$	Cost of transferring a unit of COVID-19 plasma from laboratory l to demand points n in period t	Q'''_{lnt}	The amount of blood moved from laboratory l to demand points n in period t	Continuous
$\widetilde{CA}_{jmt}$	Cost of transferring a unit of blood from temporary center j to permanent center m in period t	$Q'''''_{m'k't}$	The amount of plasma collected in blood center m' from donors k' in period t	Continuous
$\widetilde{CT}_{mlt}$	Cost of transferring a unit of blood from permanent center m to a laboratory l in period t	$Q'''''_{m'lt}$	The amount of plasma transferred from blood center m' to laboratory l in period t	Continuous
$\widetilde{CD}_{m'lt}$	Cost of transferring a plasma unit from permanent center m' to laboratory l in period t	$Q'''''''_{ln't}$	The amount of plasma transferred from laboratory l to demand points n in period t	Continuous
FR_m	Fixed cost to build blood center m	p_t	Number of interim facilities required in period t	Continuous
$FR_{m'}$	Fixed cost to build plasma center m'	XU_{jljt}	If the temporary facility in location j in period t-1 in location j_1 is in period t, it is one; otherwise, it is zero.	Binary
FU	Fixed cost to establish a temporary blood center	XR_m	If a permanent blood center is created in location m, it is one; otherwise, it is zero	Binary
$\widetilde{C}_{mk}$	Operating cost for blood collection in blood center m from a donor of group k	$XR_{m'}$	If a permanent plasma center is created in location m', it is one, and otherwise, it is zero	Binary
$\widetilde{C}_{m'k'}$	Operating cost for plasma collection in blood center m' from a donor of group k'	yu_{jkt}	If donor k is assigned to interim facility j in period t, it is one, and otherwise, it is zero	Binary
$\widetilde{C}_{jk}$	Operating cost for blood collection in interim facility j from a donor of group k	M	A very large number	Continuous
$\widetilde{capl}_{lt}$	Blood storage capacity in laboratory l in period t	YR_{mkt}	If donor k is assigned to permanent blood center m in period t, it is one, and otherwise, zero	Binary
$\widetilde{capp}_{lt}$	Plasma storage capacity in laboratory l in period t	$YR'_{m'k't}$	If donor k' is assigned to plasma permanent center m' in period t, it is one, and otherwise, zero	Binary

$$Q'_{jmt} \leq \widetilde{capf}_{mt} \forall j, m, t, \tag{14}$$

$$Q'''''_{m'lt} \leq \widetilde{capp}_{lt} \forall m', l, t, \tag{15}$$

$$Q'''''_{m'k't} \leq \widetilde{capp}_{m't} \forall m', k', t, \tag{16}$$

$$XU_{j1jt}, XR_m, XR_{m'}, YU_{jkt}, R_{mjt}, YR_{mkt}, YR_{m'k't}', \in \{0,1\} \forall m', k', t, \tag{17}$$

$$Q_{jkt}, Q''_{jmt}, Q'''_{mkt}, Q'''''_{mlt}, Q'''''_{lnt}, Q'''''_{m'kt}, Q'''''_{m'lt}, Q'''''_{ln't}, pr_t \geq 0 \forall j, m, m', k', k, n, n'. \tag{18}$$

According to the above mention constraints, the objective function in equation (1) minimizes the expected costs of the blood supply chain. These costs involve the fixed costs of establishing the facility, the operating cost of collecting blood and plasma from donors in blood centers, the cost of transporting between various stages of the supply chain, and the cost of testing blood and plasma health, respectively. Constraint (2) indicates that only one permanent or temporary blood center can receive blood from each group of donors. Constraints (3)–(5) are related to blood and plasma donation. Constraints (3) and (4) state that the group of blood donors can go to a permanent or temporary blood donation center. Limitation (5) shows that the group of plasma donors can go to a permanent plasma donation center. Constraints (6)–(8) are related to the establishment and number of temporary facilities. Limit (6) shows the number of temporary facilities required. Limitation (7) guarantees that temporary facilities are relocated to a place that has not already been located. Constraint (8) states that only one temporary or permanent center can be located in one place. Constraints (9)–(12) are related to the supply and demand of blood and plasma. Constraint (9) restricts the amount of blood donated in each cycle by each batch of donors to interim and continual centers. Constraint (10) restricts the amount of plasma donated in each period by each batch of donors in the permanent center. Constraints (11) and (12) specify, respectively, that the optimal blood and plasma demand must be met in each period. Constraints (13)–(16) show the saving capacity of blood and plasma in laboratories and permanent centers, respectively. Limitation (17) and (18) determine the nature of the problem decision variables.

3.5. Solution Approach: A Fuzzy Chance-Constrained Programming Approach. In the model provided in Section 3.4, the values of parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are uncertain. To cope with uncertainty, the fuzzy chance-constrained approach is used [11]. Accordingly, the certain equivalent of the proposed uncertain model is as follows:

$$\begin{aligned}
\min E[z] &= \sum_{m'} \mathrm{FR}_{m'}\mathrm{XR}_{m'} + \sum_{t}\mathrm{FUPR}_t + \sum_{m}\mathrm{FR}_m\mathrm{XR}_m \\
&+ \sum_{m'}\sum_{k'}\sum_{t} Q''''_{m'k't}\left(\frac{C_{m'k'(1)} + C_{m'k'(2)} + C_{m'k'(3)} + C_{m'k'(4)}}{4}\right) \\
&+ \sum_{j}\sum_{k}\sum_{t} Qjkt\left(\frac{C_{jk(1)} + C_{jk(2)} + C_{jk(3)} + C_{jk(4)}}{4}\right) \\
&+ \sum_{k}\sum_{m}\sum_{t} Q''_{mkt}\left(\frac{C_{mk(1)} + C_{mk(2)} + C_{mk(3)} + C_{mk(4)}}{4}\right) \\
&+ \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\left(\frac{CT_{mlt(1)} + CT_{mlt(2)} + CT_{mlt(3)} + CT_{mlt(4)}}{4}\right) \\
&+ \sum_{m'}\sum_{l}\sum_{t} Q''''_{m'lt}\left(\frac{CD_{m_ilt(1)} + CD_{m_ilt(2)} + CD_{m_ilt(3)} + CD_{m_ilt(4)}}{4}\right) \\
&+ \sum_{l}\sum_{n}\sum_{t} Q''_{lnt}\left(\frac{CB_{lnt(1)} + CB_{lnt(2)} + CB_{lnt(3)} + CB_{lnt(4)}}{4}\right) \\
&+ \sum_{l}\sum_{n_i}\sum_{t} Q''''_{ln't}\left(\frac{CB_{ln_it(1)} + CB_{ln_it(2)} + CB_{ln_it(3)} + CB_{ln_it(4)}}{4}\right) \\
&+ \sum_{m}\sum_{l}\sum_{t} Q''_{mlt}\left(\frac{C_{l(1)} + C_{l(2)} + C_{l(3)} + C_{l(4)}}{4}\right) \\
&+ \sum_{m'}\sum_{l}\sum_{t} Q''''_{m'lt}\left(\frac{C_{l(1)} + C_{l(2)} + C_{l(3)} + C_{l(4)}}{4}\right).
\end{aligned} \tag{19}$$

According to equations (2), (10), (17), and (18),

$$\sum_{j}\sum_{m}\sum_{t} Q''_{jmt} + \sum_{m}\sum_{l}\sum_{t} Q''_{mlt} + \sum_{l}\sum_{n}\sum_{t} Q''''_{lnt} \geq (1-\alpha)\times\sum_{n} D_{nt(3)} + (\alpha)\times\sum_{n} D_{nt(4)}\forall t, \tag{20}$$

$$\sum_{m'}\sum_{l}\sum_{t} Q''_{m'lt} + \sum_{m'}\sum_{n}\sum_{t} Q''_{m'n't} + \geq (1-\alpha)\times\sum_{n} D''_{nt(3)} + (\alpha)\times\sum_{n} D_{nt(4)}\forall t, \tag{21}$$

$$Q''_{mlt} \leq (1-\alpha)\times capl_{lt(2)} + (\alpha)\times capl_{lt(1)}\forall m, l, t, \tag{22}$$

$$Q'_{jmt} \leq (1-\alpha)\times capf_{mt(2)} + (\alpha)\times capf_{mt(1)}\forall m, l, t, \tag{23}$$

$$Q''''_{m'lt} \leq (1-\alpha)\times capp_{lt(2)} + (\alpha)\times capp_{lt(1)}\forall m', l, t, \tag{24}$$

$$Q''''_{m'k't} \leq (1-\alpha)\times capp_{m't(2)} + (\alpha)\times capp_{m't(1)}\forall m', k', t 0.5 \leq \alpha \leq 1. \tag{25}$$

Table 2: Information of demand points.

No.	Hospital name	Type of need	Number of beds
1	Namazi Hospital	Blood and plasma	780
2	Pars Hospital	Blood	45
3	Shahid Dr. Beheshti Hospital	Blood and plasma	224
4	Zeinabiyyeh Hospital	Blood	179

Table 3: Data on model parameters.

Parameters	Value
$\tilde{C}_l$	[100000, 7500]
d_{kt}	[150, 30]
$d'_{k't}$	[50, 15]
M	1000000000
$\widetilde{capl}_{lt}$	[350, 200]
$\widetilde{capp}_{lt}$	[1500, 50]
$\widetilde{capp}_{m't}$	[500, 250]
$\widetilde{capf}_{mt}$	[400, 100]
$\widetilde{CB}_{ln't}$	[3200, 1800]
$\widetilde{CA}_{jmt}$	[5000, 1500]
$\widetilde{CT}_{mlt}$	[3500, 1300]
$\widetilde{CD}_{m'lt}$	[4500, 3200]
$\widetilde{D}_{nt}$	[1000, 800]
$\widetilde{D}'_{n't}$	[500, 400]
$\widetilde{CB}_{lnt}$	[5000, 3500]
FR_m	23,000
$FR_{m'}$	25,000
FU	400
$\widetilde{C}_{mk}$	[3000, 1500]
$\widetilde{C}_{m'k'}$	[4000, 2500]
$\widetilde{C}_{jk}$	[3800, 2200]

4. Results

In current section, a real case study in the city of Shiraz is reviewed. According to validation approach the proposed model is test. For this purpose, four sample problems in certain and noncertain states are investigated, and finally, the sensitivity analysis of the goal function in relation to the model parameters is carried out. It should be noted that the proposed mathematical model was coded in GAMS 24.1.2 software on a personal computer with CPU intel Core i7 and 8 GB RAM.

4.1. Case Study. Shiraz is the fifth largest and numerus city in Iran and the most populous city in the south of the country. Due to the shortage of blood and COVID-19 plasma in Shiraz and the urgent need for blood in hospitals and medical centers, as well as plasma to help cure COVID-19 patients as soon as possible and to compensate for blood shortage and meet the rate of blood and plasma demand, it is essential to design a chain blood supply. Three points in Shiraz were considered as candidates for the establishment of temporary facilities. Donated blood in temporary centers is transferred to the blood center on Namazi Street. The blood collected in temporary and permanent centers is then transferred to Shiraz Blood Transfusion Laboratory located in Namazi Street, and after performing health test, it is given to hospitals and medical centers. Also, donors who have recovered from COVID-19 donate their plasma to the blood center on Qasrdasht Street. In this study, four hospitals were considered as demand points. Table 2 shows information of the four demand points. In this study, a one-year planning horizon is considered, and each time unit shows a four-month period and also the model parameters are given in Table 3.

Table 4: The value of the goal function in certain and uncertain states.

Amount of the objective function in certain state	Amount of the goal function in uncertain state		
	0.9	0.7	0.5
103.70	103.90	103.85	103.80

Table 4 indicates the amount of the goal function in the certain and uncertain condition. According to Table 4, as the value of the α parameter increases, the chain costs increase. Therefore, the decision maker can reduce the cost of the α parameter to reduce costs.

It is worth noting that, due to space savings, only period one is shown. As the α parameter increases, the number of potential mobile points in different periods increases to respond to the increase in demand. In the first period, at the level of $\alpha = 0.5$, mobile point 1 and at the level of $\alpha = 0.7$, in addition to the previous point, point 2, and at the level of $\alpha = 0.9$, in addition to the points of the two levels before point 3 are considered to meet the demand of hospitals.

4.2. Sample Problem. Table 5 shows the sample problems created to investigate the efficiency of the model in different dimensions.

The results of solving the problems in certain state and the fuzzy chance-constrained model for various values of α are shown in Table 6. According to this table, it is obvious that, with gaining the dimensions of the problem, the value of system costs increases, and system costs in the uncertainty state are greater than the certain state by increasing the value of α.

4.3. Sensitivity Analysis. In this section, variations in the objective function to different values of demand are evaluated. It is worth noting that, due to lack of space, the sensitivity analysis is carried out on only one parameter. For sensitivity analysis, all sample problems are considered.

Table 5: Dimensions of the sample problem.

Sample problem	Sets								
	Recovered donors	Regular donors	Temporary centers	Permanent plasma center	Permanent blood center	Laboratory	Time period	Blood demand points	Plasma demand points
1	8	13	8	2	4	3	6	6	2
2	12	13	10	3	5	5	9	10	6
3	14	17	12	4	6	7	12	14	10
4	16	20	14	5	7	9	18	18	14

Table 6: The amount of the goal function in the certain condition and uncertainty of the parameters.

Solving time (seconds)	Value of the goal function in certain conditions	Value of goal function in conditions of uncertainty						Sample problem
		Solving time (seconds)	$\alpha = 0.9$	Solving time (seconds)	$\alpha = 0.7$	Solving time (seconds)	$\alpha = 0.5$	
30	115.6733	48	115.98	45	115.97	35	115.95	1
50	116.1003	68	116.4005	65	116.3005	55	116.2295	2
70	127.2257	83	127.8675	80	127.4475	75	127.3375	3
85	128.245	108	128.24495	105	128.245	100	128.245	4

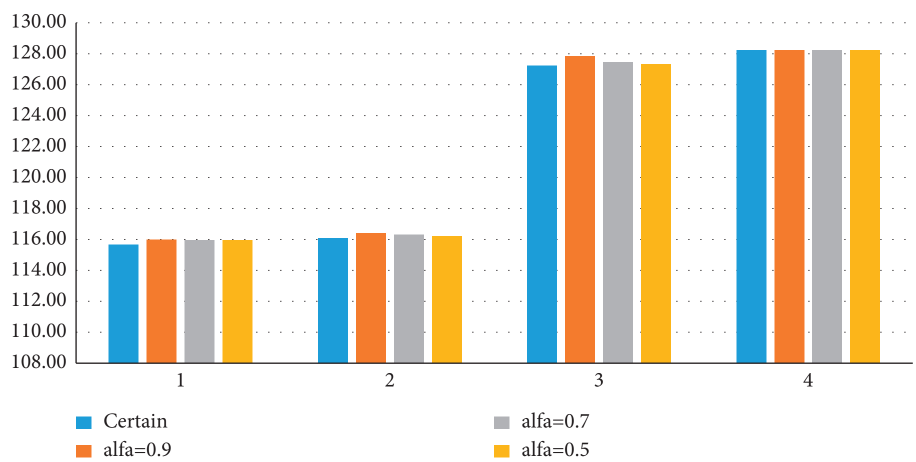

Figure 2: Variations in Z to variations in demand in certain and fuzzy chance-constrained models.

According to Figure 2, as demand increases, more blood and plasma need to be collected to meet demand, which increases operating and health testing costs and ultimately increases total system costs.

4.4. Discussion. In the event of a crisis, blood transfusions and blood products are one of the most vital and important medical emergency measures. According to the importance of blood and blood products, the source of blood supply is very limited. According to the fact that blood and blood products cannot be produced artificially in the laboratory, the only source of supply is donors. Given the importance of this rare factor, it is essential to establish a blood network in critical situations to collect blood products in the event of widespread pandemics. In this study, the presented model is able to reducing the cost of blood plasma collected during a recent pandemic outbreak. Finally, using definitive programming, model behavior is applied in real-world case study.

4.5. Managerial Insights. For implication in the real world to show implication managerial insight, issue of transfusion of blood plasma during a crisis in a crisis city has been investigated by considering the uncertain parameters of supply and transmission. The mathematical modeling presented in this study adds useful knowledge to health managers to design, modify, and evaluate the blood transfusion system in the against of the COVID-19 pandemic.

5. Conclusion and Future Suggestions

In current study, a multilevel and multiperiod MIP model is proposed for designing blood supply chain at different levels such as, permanent and temporary centers, laboratories, set of donors, and demand points considering minimization of chain costs. In the mathematical model, real-world constraints such as meeting blood and plasma demand in each period, blood and plasma storage capacity, and establishing temporary facilities are considered. Parameters of blood and plasma demand, system costs, and blood and plasma inventory storage capacity are considered uncertain. The fuzzy uncertain limited framework was used to consider with the uncertainty of the deterministic values. Finally, the efficiency of the presented model was implemented using a real case study in Shiraz. According to the main results of computational modeling, the proposed model could be calculated as follows:

(i) Value objectives function in the certain and uncertain values.
(ii) According to the results, the objective certain value is lower than uncertain value.
(iii) Uncertain value calculated is of three dimensions. According to this, the categorized objective value increased when the dimension is equal 0.5.
(iv) Finally, it shows that demand increases, more blood and plasma need to be collected to meet demand, which increases operating and health testing costs and ultimately increases total system costs.

For future research, the uncertainty of the model parameters can be controlled from other uncertainty approaches such as random and robust programming, and the results can be compared with the fuzzy chance-constrained approach. The model can also be developed in conditions of crisis.

Data Availability

The data that support the findings of this study are available from the author, upon reasonable request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Research Article

A Multiobjective Model for Optimizing Green Closed-Loop Supply Chain Network under Uncertain Environment by NSGA-II Metaheuristic Algorithm

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Nowadays, due to growing development and competitiveness in global markets of products, companies are forced to make significant efforts for supply procurement, production, and goods distribution in order to survive in the market and be able to respond to their customers' needs as quickly and cost-efficiently as possible. In this regard, supply chain management is considered a crucial indicator. This study presents a multiobjective, multifacility, closed-loop supply chain under uncertain environments considering green supply chain aspects. The model is designed with multiple products, periods, plants, customer markets, collection centers, recycle centers, distribution centers, return facilities, product recovery facilities, and suppliers. After modeling the study, the model is solved by the Nondominated Sorting Genetic Algorithms (NSGA-II) in order to rank the optimum solutions. The efficiency of the research model is indicated by the results and depicted graphs in the present study. Results show that the exact value of the triple objective functions is calculated. Also, the problem is solved in small, medium, and large dimensions. Then, the accuracy of the proposed model compared to the metaheuristic method is shown. Finally, by performing sensitivity analysis, we showed that target functions are less sensitive to reducing the capacity of centers.

1. Introduction

In the present global competition, diverse products should be made available to customers according to their demands. Customer demand for high-quality and prompt services has imposed some unprecedented pressures. Therefore, companies are incapable of handling all the tasks on their own. In this regard, supply chain management is presently considered a simplifying and economical approach to stabilizing a business. It is worth noting that capturing a higher market share is one of the goals in the supply chain. Accordingly, activities such as supply and demand planning, sourcing raw materials, product manufacturing and planning, product storage services, inventory management, distribution, delivery, and customer services are included in the supply chain in which the coordinated control and management of all these activities is the key point [1].

Supply chain management is responsible for integrating all the functions related to financial, information, and material flow in order to turn goods from the raw material into the finished product. Location-allocation decision is one of the crucial decisions in the supply chain. When the suitable number and location of facilities are selected and a proper distribution network is designed, these problems contribute much to cost reduction and access to competitive advantages in supply chain. Since in the real world, supply chains do not deal with precise and certain data regarding customer demand and prime cost in the supply chain, it is more desirable to use fuzzy sets in order to identify customer demands and prime cost in the supply chain [2]. Today, supply chain network design has been a demanding question and attracted great interest in a wide range of fields [3]. In general, open-loop supply chains include materials that are recovered by components other than the major manufacturers that have the ability to reuse these materials or products. Ring supply chains, on the other hand, depend on the concept of reusing products from customers and returning them to the original manufacturer to recover added value by reusing the entire product or part of it. Closed-loop supply chains that extend into the reverse supply chain include reproduction, reuse, repair, renovation, and recycling. They need a significant investment in resources and then the development of a collection system that takes the product back at the end of its life. Open-loop chains consist of different materials from manufacturers, and closed-loop chains focus on a specific manufacturer [4].

As mentioned above, the novelties and main contributions of the present research are as follows:

(i) Developing a mathematical model with consideration of multiple periods for the network, diversity in products, and number of facilities

(ii) Using the fuzzy approach to develop the multiobjective mathematical model

(iii) Using the NSGA-II algorithm to solve the developed model and applying the paired *t*-test and Mann–Whitney test for statistical analysis

The rest of the study is organized as follows: Section 2 presented a literature review. In Section 3, we provided a research methodology that includes mathematical model description and research solution approaches. In Section 4, we provided results that consist of main results, model validation, and sensitive analysis. In Section 5, we presented research managerial insights and finally in Section 6 conclusion and future studies are presented.

2. Literature Review

In recent years, a variety of research has been conducted on the supply chain. Ekhtiari [5] presented a three-echelon, single-product supply chain including manufacturers, distribution centers, and customers. In this supply chain, customer demands, returned products, and shipping time from distribution centers to customers are considered fuzzy variables. It is under uncertain conditions that distributors and suppliers are selected and customers are determined. Amin and Zhang [6] presented a multiobjective facility location model for a closed-loop supply chain network under uncertain demand and return. This closed-loop supply chain network includes both forward and reverses supply chains. In their study, they investigated a supply chain network consisting of multiple plants, collection centers, demand markets, and products. In addition, a mixed-integer linear programming model is used to minimize the total cost. Latha Shankar et al. [7] presented the location and allocation decisions for a four-echelon supply chain network consisting of suppliers, plants, distribution centers, and customers. Using a multiobjective swarm particle optimization algorithm, this model minimizes the total cost of production, setup, and shipment in the supply chain network and maximizes the fill rate. Mousavi and Niaki [8] presented a capacitated location-allocation problem with uncertain customer locations and demands. The customer demands were assumed fuzzy, customer locations followed a normal probability distribution, and the genetic algorithm was applied to solve the model. Zareian Jahromi et al. [9] designed a sustainable multiproduct closed-loop logistic network in four echelons of supply, production, distribution, and customer under uncertain conditions of customer demands, interfaculty transportation costs, and facility-related operational costs. They developed a model in order to maximize social impacts and profit based on two criteria, i.e., the number of job opportunities created and the number of lost days, and to minimize environmental impacts based on the carbon emission index. Jahani et al. [10] aimed to maximize total profit, taking into consideration the demand and price uncertainty and their correlation as two major risk factors. Mazaheri et al. [11] aimed to maximize the supply chain profit, minimize the suppliers' shortages, minimize the financial risk, and finally, maximize the customer satisfaction. The mathematical model is formulated and solved using the LINGO software. The results indicate that the supply chain network can expand and gain significantly increased profit. Anand and Sudhakara Pandian [12] presented a new algorithm for customer-to-customer supply chain management considering cost reductions in quantity rebates for inbound and outbound logistics transportation. In their article, a unique, six-phase approximation procedure is applied to simplify distance calculation details and to develop an algorithm in order to solve the supply chain management problems using a nonlinear optimization technique. Fathi et al. [13] considered uncertainty in the quality of returned products. The main objective of this study was to apply the stochastic planning model and maximize the expected profit for all the scenarios of quality status. Zare Mehrjerdi and Lotfi [14]; presented a two-stage, mixed-integer linear programming is used for modeling and a robust counterpart model is utilized to encounter the demand uncertainties. The Conditional Value-at-Risk criterion is considered to model risk and compared with Value-at-Risk and average absolute deviation. Sabouhi et al. [15] presented an optimization approach for a sustainable and resilient supply chain design with regional considerations. They applied a metaheuristic method to solve the developed model. In the study by Lotfi et al. [16],, for the first time, the aspects of stability, flexibility, robustness, and transient risk in the closed-loop supply chain are considered. For this purpose, a complex integer linear programming model is presented. In addition, a robust model of this problem is presented to consider the uncertainty in the problem. In Gerdrodbari et al. [17], a bi-objective mixed-integer linear programming (MILP) model is proposed to design a multi-level, multi-period, multiproduct closed-loop supply chain (CLSC) for timely production and distribution of perishable products, taking into account the uncertainty of demand. To face the model uncertainty, the robust optimization (RO) method is utilized. Moreover, to solve and validate the bi-objective model in small-size problems, the epsilon-constraint method (EC) is presented. On the other hand, a Nondominated Sorting Genetic Algorithm (NSGA-II) is developed for solving large-size problems. In Zadeh et al. [18], a multiobjective mixed-integer linear programming model is developed for a green multi-echelon closed-loop supply chain network design under uncertainty. Moreover, a partial disruption is considered for distribution centers that have not been studied enough in previous works. The fuzzy credibility constraint approach is applied to cover uncertainty. In the following, the epsilon-constraint method is presented to solve and validate the model in small-sized instances. Moreover, a Nondominated Sorting Genetic Algorithm is developed for solving large-sized problems. Safaei et al. [19] addressed a new multi-echelon multi-period closed-loop supply chain network to minimize the total costs of the network. The echelons include suppliers, manufacturers, distribution centers, customers, and recycling and recovery units of components in the proposed network. Also, a Mixed-Integer Linear Programming (MILP) model considering factories' vehicles and rental cars of transportation companies is formulated for the proposed problem. Momenitabar et al. [20] considered the impacts of the backup suppliers and lateral transshipment/resupply simultaneously on designing a Sustainable Closed-Loop Supply Chain Network (SCLSCN) to decrease the shortage that may occur during the transmission of produced goods in the network. In this manner, the fuzzy multiobjective mixed-integer linear programming model is proposed to design an efficient SCLSCN resiliently.

2.1. Research Gap. According to studies, there is a lack of development of a mathematical model by considering multiple courses for the network, variety of products, and the number of available facilities that will be able to consider the uncertainty parameters in a chain. For this purpose, in this research, a fuzzy approach is used to develop a multiobjective mathematical model. Also, the NSGA-II algorithm is used to solve the developed model, and paired *t*-test and Mann–Whitney test are used for statistical analysis. Table 1 categorizes previous studies.

3. Research Methodology

3.1. Problem Statement. Considering uncertain prices and using a transportation model to reduce transportation costs, the present study introduces a green closed-loop supply chain (CLSC) problem. In the CLSC network of the present study, the forward chain contains three levels, and there are three echelons in the reverse chain as well. The forward supply chain includes the procurement of the materials and components (supply phase), production of new products (production phase), and distribution of the new products (distribution phase). On the other hand, the reverse supply chain includes collection of end-of-life products (collection phase), inspection and recovery of returned products (recovery phase), and distribution of recovered products (redistribution phase). Figure 1 illustrates these levels.

In the first level of this chain, raw materials and components required for plants are supplied by reverse centers and suppliers. According to the allowed returned product rate, the components of end-of-life products (EOLPs) are served to supply plants. In the event of any shortage in supplying the required components from reverse centers, plants can procure their required components from suppliers. The recovered components must satisfy the minimum specifications for reuse in plants. In the second level, plants manufacture new products and deliver them to distribution centers where products are delivered to customers based on their demand variety. The reverse supply chain process starts with customer returns. In the first step of the reverse chain, the end-of-life products are collected in collection centers and sent to reverse centers for sorting, inspection, and decision making. In the second step, the best decisions are made for the inspected products (the decisions on whether to recover the products or dismount the parts). Product recovery includes refurbishing and minor repairing of products while dismounting the parts includes disassembling a product to its components in order to reuse it in certain facilities. Reverse centers send the components from disassembled products to plants in order to satisfy their demands. On the other hand, based on their quality level, some components can be decomposed into their materials and sold to external suppliers to gain profit for the supply chain, although less significantly. In the final step of the reverse chain, recovery facilities run the repairing and refurbishing operations and send the recovered products to distribution centers after quality control and packaging.

In the present study, the closed-loop supply chain (CLSC) model is applied to manufacture and recover a number of products under various demands and return rates. Each product is made of different numbers and kinds of components, and each component is made of different numbers and quantities of materials. Considering the relationship between retrieve price and return rate leads us to a multi-objective guideline for maximizing the level of satisfaction and profitability. In the present study, the level of satisfaction is defined as adjusting the retrieved price and desirable return rate, in a way that the price for returned products provides satisfaction. The corresponding CLSC network is illustrated in Figure 1.

3.2. Picture of Problem Statement. The uncertainty related to the selling price and purchase price of a product is investigated in this section. We assume that there are acceptable upper and lower bounds of prices for sellers and buyers. Here, we have two different perspectives about the satisfaction of both parties in a trade: first, customers and buyers who purchase a (new and/or recovered) product, and second, customers who are sellers of EOLPs to reverse centers through collection centers. Therefore, two different roles, buyer and seller, are to be investigated for customers in a closed-loop supply chain. A summary of the corresponding conditions in our model is given as follows:

Customers are buyers of recovered or new products and distribution centers play the role of sellers. The agreed price

Table 1: Literature review.

Authors	Year of publication	Elements			
		Multiproduct	Multistage	Uncertainty	Multiobjective
Ekhtiari	2010	*	*	*	—
Zhang and Amin	2013	—	—	*	*
Shankar et al.	2013	—	*	—	*
Mousavi and Niaki	2013	—	—	*	—
Zareian et al.	2014	*	*	—	*
Mazaher et al.	2019	—	—	—	*
Mehrjerdi and Lotfi	2019	—	*	*	—
Gerdrodbari et al.	2021	*	*	—	*
Keshmiry Zadeh et al.	2022	—	*	*	*

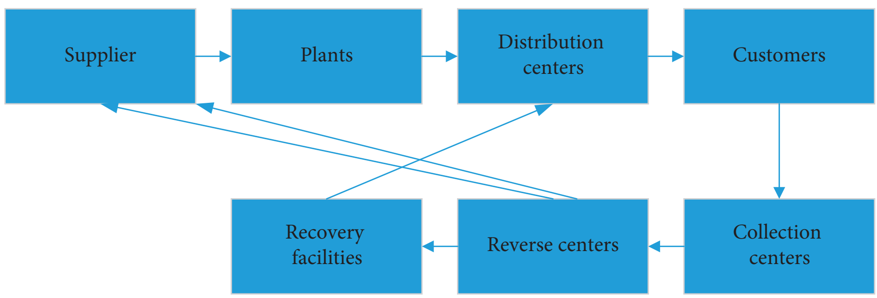

Figure 1: Levels of the corresponding supply chain in the present study.

of recovered products can be within the range of minimum selling price and ideal selling price for distribution centers, and a membership function can represent the degree of satisfaction for distribution centers. Similarly, the agreed price of the recovered product can be limited within the range of ideal purchase price and maximum purchase price, and a membership function can represent the degree of satisfaction for customers.

A number of parameters for pricing recovered products are as follows:

P^r is the agreed price of recovered products

$P^{r\min}$ is the minimum selling price for distribution centers

P^{rdid} is the ideal selling price for distribution centers

P^{rcid} is the ideal purchase price for customers

$P^{r\max}$ is the maximum purchase price for customers

We assume that the membership function is linear within the value range of minimum selling price and ideal selling price for distribution centers. Similarly, a linear pattern is assumed to exist between ideal and maximum purchase prices for customers. Here, we have two different conditions for product i:

(1) $P^{rdid} < P^{rcid}$ condition: this represents the condition in which the ideal price for distribution centers is higher than the ideal purchase price for customers. In this situation, it is hard to satisfy both parties in terms of product price. Here, there is a single acceptable price that can meet the expectations of both parties. The intersection point of membership function shows the best choice with the highest degree of satisfaction. We assumed that there is at least one intersection point in which the expected price of customers and distribution centers is satisfied.

(2) $P^{rdid} \geq P^{rcid}$ condition: this represents the condition in which the ideal selling price of contribution centers is lower than the ideal purchase price of customers. In this case, it is an easy job to satisfy both parties in the trade.

Equation (1) shows the membership function of recovered products for the degree of satisfaction among distribution centers and customers.

$$\mu^r = \begin{cases} 0, & p^r < p^{r\min}, \\ \dfrac{p^r - p^{r\min}}{p^{r\text{did}} - p^{r\min}}, & p^{r\min} \leq p^r \leq p^{r\text{did}}, \\ 1, & p^{r\text{did}} \leq p^r \leq p^{r\text{cid}}, \\ \dfrac{p^{r\max} - p^r}{p^{r\max} - p^{r\text{cid}}}, & p^{r\text{cid}} \leq p^r \leq p^{r\max}, \\ 0, & p^r \geq p^{r\max}. \end{cases} \tag{1}$$

Similar mathematical relations are valid for the condition in which customers are buyers of a new product and distribution centers are sellers. The agreed price for a new product can be within the range of minimum selling price and ideal purchase price for distribution centers, and a membership function can represent this price in order to express the degree of satisfaction for distribution centers. Similarly, the agreed price of a new product can be within the value range of the ideal purchase price and maximum purchase price for customers, and a membership function can represent the degree of satisfaction among customers.

A number of parameters for pricing new products are as follows:

P^n agreed price of new products
$P^{n\min}$ minimum selling price for distribution centers
P^{ndid} ideal selling price for distribution centers
P^{ncid} ideal purchase price for customers
$P^{n\max}$ maximum purchase price for customers

Equation (2) represents the membership function for distribution centers and customers' degree of satisfaction from new products.

$$\mu^n = \begin{cases} 0, & p^n < p^{n_{\min}}, \\ \dfrac{p^n - p^{n_{\min}}}{\mathrm{p}^{n_{\mathrm{did}}} - p^{n_{\min}}}, & p^{n_{\min}} \le p^n \le p^{n_{\mathrm{did}}}, \\ 1, & p^{n_{\mathrm{did}}} \le p^n \le p^{n_{\mathrm{cid}}}, \\ \dfrac{p^{n_{\max}} - p^n}{p^{n_{\max}} - p^{n_{\mathrm{cid}}}}, & p^{n_{\mathrm{cid}}} \le p^n \le p^{n_{\max}}, \\ 0, & p^n \ge p^{n_{\max}}. \end{cases} \quad (2)$$

In the reverse supply chain, customers are sellers of returned products while reverse centers are buyers of these products. It is clear that both customers and reverse centers consider an acceptable limit for the price of returned products. On one hand, the higher the selling price of a product, the more satisfied the customers. For reverse centers on the other hand, it is more desirable that the purchase price of returned products is as low as possible. The symbols for membership function are as follows:

P^e agreed price of returned products
P^{erid} ideal purchase price for reverse centers
$P^{e\max}$ maximum purchase price of returned products for reverse centers
P^{ecid} ideal selling price of returned products for customers
$P^{e\min}$ minimum selling price of returned products for customers

Equation (3) shows the satisfaction behavior of customers and reverse centers.

$$\mu^e = \begin{cases} 0, & p^e < p^{e_{\min}}, \\ \dfrac{p^e - p^{e_{\min}}}{\mathrm{p}^{e_{\mathrm{cid}}} - p^{e_{\min}}}, & p^{e_{\min}} \le p^e \le p^{e_{\mathrm{did}}}, \\ 1, & p^{e_{\mathrm{cid}}} \le p^e \le p^{e_{\mathrm{rid}}}, \\ \dfrac{p^{e_{\max}} - p^e}{p^{e_{\max}} - p^{e_{\mathrm{rid}}}}, & p^{e_{\mathrm{rid}}} \le p^e \le p^{e_{\max}}, \\ 0, & p^e \ge p^{e_{\max}}. \end{cases} \quad (3)$$

3.3. Fuzzy Multi-Objective CLSC Model. The main purpose of the presented model is to describe a designed CLSC including customers, collection centers, reverse centers, plants, distribution centers, and recovery facilities. In the present study, we formulate a multi-period, multi-echelon, and multiproduct CLSC model which involves all activities from suppliers to recovery facilities. The model aims to achieve the maximum level of satisfaction and profitability in the network.

(i) Notation

Sets and indices are as follows:

P: set of possible locations for plants
D: set of possible locations for distribution centers
R: set of possible locations for reverse centers
J: set of possible locations for collection centers
C: set of possible locations for customers
T: periods
I: set of product types
N: set of component types
M: set of material types
G: set of transportation vehicles

Decision variables are as follows:

Y_{cjt} = index for assigning customer c to collection center j in period t
Y_{jrt} = index for assigning collection center j to reverse center r in period t
Y_{rft} = index for assigning reverse center r to recovery facility f in period t
Y_{rpt} = index for assigning reverse center r to plant p in period t
Y_{fdt} = index for assigning recovery facility f to distribution center d in period t
Y_{pdt} = index for assigning plant p to distribution center d in period t
Y_{dct} = index for assigning distribution center d to customer c in period t
Z_{jt} = index for opening collection center j in period t
Z_{rt} = index for opening reverse center r in period t
Z_{ft} = index for opening recovery facility f in period t
Z_{pt} = index for opening plant p in period t
Z_{dt} = index for opening distribution center d in period t

X_{ridct} = quantity of recovered products sent from distribution center d to customer c in period t
X_{nidct} = quantity of new products sent from distribution center d to customer c in period t
X_{icjt} = quantity of returned products from customer c to collection center j in period t
X_{ijrt} = quantity of returned products from collection center j to reverse center r in period t
X_{irft} = quantity of returned products from reverse center r to recovery facility f in period t
X_{irpt} = quantity of components and compounds from reverse center r to plant p in period t
X_{ifdt} = quantity of recovered products from recovery facility f to distribution center d in period t
X_{ipdt} = quantity of new products from plant p to distribution center d in period t
X_{mrt} = quantity of materials prepared in reverse center r in period t
X_{npt} = quantity of outsourced components and compounds for plant p in period t
XV_{icjt} = number of vehicles to transport product i from customer c to collection center j in period t
XV_{ijrt} = number of vehicles to transport product i from collection center j to reverse center r in period t
XV_{irft} = number of vehicles to transport product i from reverse center r to recovery facility f in period t
XV_{ifdt} = number of vehicles to transport product i from recovery facility f to distribution center d in period t
XV_{ipdt} = number of vehicles to transport product i from plant p to distribution center d in period t
XV_{nrpt} = number of vehicles to transport component n from reverse center r to plant p in period t
XV^{n}_{idct} = number of vehicles to transport new product i from distribution center d to customer c in period t
XV^{T}_{idct} = number of vehicles to transport returned product i from distribution center d to customer c in period t

Parameters are as follows:

TF_g = fixed transportation cost when vehicle g is selected for transportation
TV_g = variable transportation cost when vehicle g is selected for transportation
GHG_g = quantity of CO_2 generated by vehicle g per unit of distance
GHL = acceptable greenhouse gas emission limit
WT = permitted amount of waste disposal by each facility
WP = percentage of waste production in each facility
Θ = maximum number of periods
W^{dm} = waste production rate for remanufacturing
W^{di} = waste production rate for disassembling the components
W^{rr} = waste production rate for refurbishing/renovating the products
d_{cj} = distance between customer c and collection center j
d_{jr} = distance between collection center j and reverse center r
d_{rf} = distance between reverse center r and recovery facility f
d_{rp} = distance between reverse center r and plant p
d_{pd} = distance between plant p and distribution center d
d_{fd} = distance between recovery facility f and distribution center d
d_{dc} = distance between distribution center d and customer c
C^{sc}_{irt} = cost of each sorting and classifying unit
C^{di}_{irt} = cost of each dissembling unit
C^{dm}_{irt} = cost of each remanufacturing unit
C^{rr}_{ift} = cost of each refurbishing/renovating unit
C^{dp}_{irt} = cost of each waste disposal unit in reverse center r
C^{df}_{ift} = cost of each waste disposal unit in recovery facility f
C^{pr}_{ipt} = cost of each production unit
C^{h}_{idt} = cost of each handling unit for products in distribution center d
v_i = volume of each unit of product i (m^3)
b_j = maximum capacity of collection center j
b_r = maximum capacity of reverse center r
b_d = maximum capacity of distribution center d
b_p = maximum capacity of plant p
b_f = maximum capacity of recovery facility f
c^s_j = cost of setting up collection center j
c^s_r = cost of setting up reverse center r
c^s_d = cost of setting u distribution center d
c^s_p = cost of setting up plant p
c^s_j = cost of setting up recovery facility f
c^f_j = fixed cost of opened collection center j
c^f_r = fixed cost of opened reverse center r
c^f_d = fixed cost of opened distribution center d
c^f_p = fixed cost of opened plant p
c^f_f = fixed cost of opened recovery facility f
c^p_i = penalty for each unit of unsatisfied demand
r^{di}_t = percentage of used products suitable for disassembling and demounting
r^{dm}_t = percentage of used products suitable for remanufacturing
r^{rr}_t = percentage of used products suitable for refurbishing/renovating
p^o_n = price of purchasing each unit of component n from market
p^e_i = purchase price for each unit of returned products
p^m_m = selling price for each unit of material m
p^n_i = selling price for each unit of new products

p_i^r = selling price for each unit of recovered products
q_{in}^c = quantity of component n in product i
q_{nm}^m = quantity of material m and component n
D_{ict}^n = quantity of customer demands for new products
D_{ict}^r = quantity of customer demands for returned products

The essential abbreviations are as follows:

TREV = total revenue of the supply chain
TSC = total setup cost
TFC = total fixed cost
TPC = total process cost
TPUC = total purchase cost
TTC = total transportation cost
THC = total handling cost
TPEC = total penalty cost

(ii) Mathematical Modeling

Here, we consider two conflicting objectives presented as follows: the first objective is to maximize the degree of satisfaction for both parties regarding CLSC. This degree of satisfaction is obtained based on the selling and purchase prices of products. TS represents the total degree of satisfaction for customers, distribution centers, and reverse centers:

$$TS = \sum_{i\in I}\mu_i^r + \sum_{i\in I}\mu_i^n + \sum_{i\in I}\mu_i^e. \tag{4}$$

The second objective is to maximize the total profit of the whole chain.

$$\begin{aligned}\text{PROFIT} = {} & \text{TREV} - \text{TSC} - \text{TFC} - \text{TPC} - \text{TPUC} \\ & - \text{TTC} - \text{THC} - \text{TPEC}.\end{aligned} \tag{5}$$

Equation (5) represents the total profit of the whole chain. This equation is obtained by subtracting the revenue and expenses of the chain. Each part of the above objective function is presented in detail as follows:

$$\begin{aligned}\text{TREV} = {} & \sum_{d\in D}\sum_{i\in I}\sum_{t\in T}\sum_{c\in C} P_i^n X_{\text{idct}}^n + \sum_{d\in D}\sum_{i\in I}\sum_{t\in T}\sum_{c\in C} P_i^r X_{\text{idct}}^r \\ & + \sum_{d\in D}\sum_{i\in I}\sum_{t\in T}\sum_{c\in C} P_m^m X_{\text{mrt}}^m.\end{aligned} \tag{6}$$

Equation (6) represents the total revenue of the whole chain. This revenue can be obtained from three sections including selling new products to customers, selling returned products to customers, and selling product materials by reverse centers, respectively.

$$\begin{aligned}TSC = {} & \sum_{t\in T}\sum_{j\in J} c_j^s\left(Z_{jT} - Z_{j(T-1)}\right) + \sum_{t\in T}\sum_{r\in R} c_r^s\left(Z_{rT} - Z_{r(T-1)}\right) \\ & + \sum_{t\in T}\sum_{p\in P} c_p^s\left(Z_{pT} - Z_{p(T-1)}\right) \\ & + \sum_{t\in T}\sum_{f\in F} c_f^s\left(Z_{fT} - Z_{f(T-1)}\right) + \sum_{t\in T}\sum_{d\in D} c_d^s\left(Z_{dT} - Z_{d(T-1)}\right).\end{aligned} \tag{7}$$

Equation (7) shows the total setup cost for each facility in the chain.

$$\begin{aligned}\text{TFC} = {} & \sum_{j\in J} c_j^f \sum_{t\in T} Z_{jT} + \sum_{r\in R} c_r^f \sum_{t\in T} Z_{rT} + \sum_{p\in P} c_p^f \sum_{t\in T} Z_{pT} \\ & + \sum_{f\in F} c_f^f \sum_{t\in T} Z_{fT} + \sum_{d\in D} c_d^f \sum_{t\in T} Z_{dT}.\end{aligned} \tag{8}$$

Equation (8) represents the total fixed cost of the chain.

$$\begin{aligned}TPC = {} & \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{j\in J} c_{\text{irt}}^{sc} X_{\text{ijrt}} + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{j\in J} c_{\text{irt}}^{di} r_t^{di} X_{\text{ijrt}} \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{f\in F} c_{\text{ift}}^{rr} X_{\text{irft}} \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{j\in J} c_{\text{irt}}^{dm} r_t^{di} r_t^{dm} X_{\text{ijrt}} \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{p\in P}\sum_{d\in D} c_{\text{ipt}}^{pr} X_{\text{ipdt}} + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{f\in F} c_{\text{ift}}^{df} w^{rr} X_{\text{irf}t} \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{j\in J} c_{\text{irt}}^{dp} w^{dm} r_t^{di} X_{\text{ijrt}} \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{r\in R}\sum_{j\in J} c_{\text{irt}}^{dp} w^{di} r_t^{dm} r_t^{di} X_{\text{ijrt}}.\end{aligned} \tag{9}$$

Equation (9) represents the CLSC total process cost which includes the cost of sorting products in reverse centers, cost of each disassembling and dismounting unit, cost of each remanufacturing unit, cost of each refurbishing unit, cost of each production unit in plants, cost of each disposal unit in the stage of disassembling components in reverse centers, cost of each disposal unit in the stage of remanufacturing components, and cost of disposal in refurbishing and recovery centers.

$$\text{TPUC} = \sum_{t\in T}\sum_{n\in N}\sum_{d\in D}\sum_{c\in C} p_n^o X_{\text{npt}} + \sum_{t\in T}\sum_{i\in I}\sum_{d\in D}\sum_{c\in C} p_i^e X_{\text{icjt}}. \tag{10}$$

Equation (10) represents the total purchase cost of the chain in a way that this cost includes purchasing components and returned products from customers.

$$\begin{aligned}\text{TTC} = {} & \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{r\in R}\sum_{c\in C}\sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{n\in N} TF_g\left(XV_{\text{icjt}} + XV_{\text{ijrt}} + XV_{\text{irft}} + XV_{\text{ifdt}} + XV_{\text{ipdt}} + XV_{\text{nrpt}} + XV_{\text{idct}}^n + \text{XV}_{\text{idct}}^{\text{r}}\right) \\ & + \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{c\in C}\sum_{r\in R}\sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{n\in N} TV_g\left(d_{cj}XV_{\text{icjt}} + d_{jr}XV_{\text{ijrt}} + d_{rf}XV_{\text{irft}} + d_{fd}XV_{\text{ifdt}} + d_{pd}XV_{\text{ipdt}} + d_{rp}XV_{\text{nrpt}} + d_{dc}XV_{\text{idct}}^n + d_{dc}XV_{\text{idct}}^r\right).\end{aligned} \tag{11}$$

Equation (11) represents the total transportation cost in the chain. This cost is obtained from two fixed and variable costs.

$$\mathrm{THC} = \sum_{t\in T}\sum_{i\in I}\sum_{d\in D} c^{h}_{\mathrm{idt}}\left(\sum_{f\in F} X_{\mathrm{ifdt}} + \sum_{p\in P} X_{\mathrm{ipdt}} - \sum_{c\in C} X^{n}_{\mathrm{idct}} - \sum_{c\in C} X^{r}_{\mathrm{idct}}\right). \tag{12}$$

Equation (12) shows the handling cost which is provided in distribution centers by plants and recovery facilities.

$$\mathrm{TPEC} = \sum_{t\in T}\sum_{i\in I}\sum_{c\in C} c^{p}_{i}\left(D^{n}_{\mathrm{ict}} - \sum_{d\in D} X^{n}_{\mathrm{idct}} + D^{r}_{\mathrm{ict}} - \sum_{d\in D} X^{r}_{\mathrm{idct}}\right). \tag{13}$$

Equation (13) represents the penalties of the chain.

In addition, the constraints of the model are as follows:

$$\sum_{t\in T} z_{jt}, \quad \le \forall j \in J, \tag{14}$$

$$\sum_{\mathrm{t}\in \mathrm{T}} z_{rt}, \quad \le \forall \mathrm{r} \in \mathrm{R}, \tag{15}$$

$$\sum_{t\in T} z_{pt}, \quad \le \forall p \in P, \tag{16}$$

$$\sum_{t\in T} z_{dt}, \quad \le \forall d \in D, \tag{17}$$

$$\sum_{t\in T} z_{ft}, \quad \le \forall f \in F. \tag{18}$$

In equations (14) to (18), a maximum period is set for each facility.

$$\sum_{j\in J} z_{jt} \ge 1, \quad \forall t \in T, \tag{19}$$

$$\sum_{r\in R} z_{rt} \ge 1 \forall t \in T, \tag{20}$$

$$\sum_{p\in P} z_{pt} \ge 1, \quad \forall t \in T, \tag{21}$$

$$\sum_{d\in D} z_{dt} \ge 1, \quad \forall t \in T, \tag{22}$$

$$\sum_{f\in F} z_{ft} \ge 1, \quad \forall t \in T. \tag{23}$$

In equations (19) to (23), we assumed that there is at least one facility of each type in every period.

$$Z_{j(t+1)} - Z_{jt} \ge 0 \quad \forall t \in T, \forall j \in J, \tag{24}$$

$$Z_{r(t+1)} - Z_{rt} \ge 0 \quad \forall t \in T, \forall r \in R, \tag{25}$$

$$Z_{p(t+1)} - Z_{pt} \ge 0 \quad \forall t \in T, \forall p \in P, \tag{26}$$

$$Z_{f(t+1)} - Z_{ft} \ge 0 \quad \forall t \in T, \forall f \in F, \tag{27}$$

$$Z_{d(t+1)} - Z_{dt} \ge 0 \quad \forall t \in T, \forall d \in D. \tag{28}$$

In equations (24) to (28), we provided the final constraints for facilities. If the model decides to open a facility in a certain period, the model will continue with the same facility. The second class of constraints is allocation constraints presented as follows:

$$\sum_{j\in J} Y_{cjt} \ge 1 \quad \forall c \in C, \forall t \in T, \tag{29}$$

$$\sum_{d\in D} Y_{dct} \ge 1 \quad \forall c \in C, \forall t \in T. \tag{30}$$

Equation (29) expresses that in each period, the products collected from customers must be retransferred to a collection center. Similarly, equation (30) expresses that in each period, only one distribution center should be allocated to each customer.

$$Y_{\mathrm{jrt}} \le Z_{jt} \quad \forall j \in J, \forall r \in R, \forall t \in T, \tag{31}$$

$$Y_{\mathrm{jrt}} \le Z_{rt} \quad \forall j \in J, \forall r \in R, \forall t \in T, \tag{32}$$

$$Y_{\mathrm{rpt}} \le Z_{pt} \quad \forall p \in P, \forall r \in R, \forall t \in T, \tag{33}$$

$$\mathrm{Y}_{\mathrm{rpt}} \le \mathrm{Z}_{\mathrm{rt}} \quad \forall p \in P, \forall r \in R, \forall t \in T, \tag{34}$$

$$Y_{\mathrm{pdt}} \le Z_{pt} \quad \forall p \in P, \forall d \in D, \forall t \in T, \tag{35}$$

$$Y_{\mathrm{pdt}} \le Z_{dt} \quad \forall p \in P, \forall d \in D, \forall t \in T, \tag{36}$$

$$Y_{\mathrm{fdt}} \le Z_{dt} \quad \forall f \in F, \forall d \in D, \forall t \in T, \tag{37}$$

$$Y_{\mathrm{fdt}} \le Z_{ft} \quad \forall f \in F, \forall d \in D, \forall t \in T, \tag{38}$$

$$Y_{\mathrm{rft}} \le Z_{rt} \quad \forall f \in F, \forall r \in R, \forall t \in T, \tag{39}$$

$$Y_{\mathrm{rft}} \le Z_{ft} \quad \forall f \in F, \forall r \in R, \forall t \in T. \tag{40}$$

In equations (31) to (40), we defined that each facility can be only allocated to a single type of other facilities. Another group of constraints is capacity constraints described as follows:

$$\sum_{\mathrm{i}\in\mathrm{I}}\sum_{c\in C} X_{\mathrm{icjt}}\vartheta_i \le b_j Z_{jt} \quad \forall j \in J, \forall t \in T, \tag{41}$$

$$\sum_{i\varepsilon I}\sum_{j\varepsilon J} X_{\mathrm{ijrt}}\vartheta_i \le b_r Z_{rt} \quad \forall r \in R, \forall t \in T, \tag{42}$$

$$\sum_{i\varepsilon I}\sum_{d\varepsilon D} X_{\mathrm{ipdt}}\vartheta_i \le b_p Z_{pt} \quad \forall p \in P, \forall t \in T, \tag{43}$$

$$\sum_{i\varepsilon I}\sum_{r\varepsilon R} X_{\mathrm{irft}}\vartheta_i \le b_f Z_{ft} \quad \forall f \in F, \forall t \in T, \tag{44}$$

$$\sum_{i\in I}\left[\sum_{f\in F} X_{\text{ifdt}} + \sum_{p\in P} X_{\text{ipdt}}\right], \quad \vartheta_i \le b_d Z_{dt}\ \forall d \in D,\ \forall t \in T. \tag{45}$$

Constraints (41) to (45) are capacity constraints that show the limited capacity of each facility. Every product has its own specific capacity which is of great importance for the capacity of each facility. Another group of constraints is green constraints which are presented as follows:

$$\sum_{i\in I}\sum_{g\in G} XV_{\text{icjtg}}\text{GHG}_g d_{cj} \le \text{GHL}_{jt} \quad \forall j \in J,\ \forall t \in T,\ \forall c \in C, \tag{46}$$

$$\sum_{j\in J}\sum_{g\in G} XV_{\text{ijrtg}}\text{GHG}_g d_{jr} \le \text{GHL}_{rt} \quad \forall r \in R,\ \forall t \in T,\ \forall i \in I, \tag{47}$$

$$\sum_{f\in F}\sum_{g\in G} XV_{\text{irftg}}\text{GHG}_g d_{rf} \le \text{GHL}_{ft} \quad \forall i \in I,\ \forall t \in T,\ \forall r \in R, \tag{48}$$

$$\sum_{d\in D}\sum_{g\in G} XV_{\text{ifdtg}}\text{GHG}_g d_{fd} \le \text{GHL}_{dt} \quad \forall i \in I,\ \forall t \in T,\ \forall f \in F, \tag{49}$$

$$\sum_{d\in D}\sum_{g\in G} XV_{\text{ipdtg}}\text{GHG}_g d_{cj} \le \text{GHL}_{dt} \quad \forall j \in J,\ \forall t \in T,\ \forall p \in P, \tag{50}$$

$$\sum_{p\in P}\sum_{g\in G} XV_{\text{nrptg}}\text{GHG}_g d_{cj} \le \text{GHL}_{pt} \quad \forall n \in N,\ \forall t \in T,\ \forall r \in R, \tag{51}$$

$$\sum_{c\in C}\sum_{g\in G}\left(XV^n_{\text{idctg}} + XV^r_{\text{idctg}}\right)\text{GHG}_g d_{pd} \le \text{GHL}_{ct} \quad \forall c \in C,\ \forall t \in T. \tag{52}$$

Constraints (46) to (52) express that transportation vehicles for each type of facility are permitted to generate a certain amount of greenhouse gases.

$$\sum_{c\in C}\sum_{i\in I}\sum_{t\in T} X_{\text{icjt}} WP_{ij} \le WT_j \quad \forall j \in J, \tag{53}$$

$$\sum_{j\in J}\sum_{i\in I}\sum_{t\in T} X_{\text{ijrt}} WP_{ir} \le WT_r \quad \forall r \in R, \tag{54}$$

$$\sum_{r\in R}\sum_{i\in I}\sum_{t\in T} X_{\text{irft}} WP_{if} \le WT_f \quad \forall f \in F, \tag{55}$$

$$\sum_{r\in R}\sum_{i\in I}\sum_{t\in T} X_{\text{irpt}} WP_{ip} \le WT_p \quad \forall p \in P, \tag{56}$$

$$\sum_{i\in I}\sum_{t\in T}\left(X_{\text{ifdt}} + X_{\text{ipdt}}\right) WP_{ip} \le WT_d \quad \forall d \in D,\ \forall f \in F,\ \forall p \in P, \tag{57}$$

$$\sum_{d\in D}\sum_{i\in I}\sum_{t\in T}\left(X^n_{\text{idct}} + X^r_{\text{idct}}\right) WP_{ic} \le WT_c \quad \forall c \in C, \tag{58}$$

$$\sum_{n\in N}\sum_{t\in T} X_{\text{npt}} WP_{np} \le WT_p \quad \forall p \in P. \tag{59}$$

Constraints (53) to (59) express that each facility is permitted to produce a certain amount of waste.

The other group of constraints is balanced constraints presented as follows:

$$\sum_{c\in C} X_{\mathrm{icjt}} \geq \sum_{r\in R} X_{\mathrm{ijrt}} \quad \forall i \in I, \forall j \in J, \forall t \in T, \tag{60}$$

$$\sum_{f\in F} X_{\mathrm{irft}} \leq r_t^{rr} \sum_{j\in J} X_{\mathrm{irjt}} \quad \forall i \in I, \forall r \in R, \forall t \in, \tag{61}$$

$$\sum_{p\in P} X_{\mathrm{nrpt}} \leq r_t^{di} \sum_{j\in J} \sum_{i\in I} X_{\mathrm{irjt}} q_{in}^{c} \quad \forall n \in N, \forall r \in R, \forall t \in, \tag{62}$$

$$\sum_{p\in P} X_{\mathrm{nrpt}} + X_{\mathrm{npt}} = \sum_{d\in D} \sum_{i\in I} X_{\mathrm{ipdt}} q_{\mathrm{in}}^{c} \quad \forall n \in N, \forall d \in D, \forall t \in, \tag{63}$$

$$\sum_{f\in F} X_{\mathrm{ifdt}} \geq \sum_{c\in C} X_{\mathrm{idct}}^{r} \quad \forall i \in I, \forall d \in D, \forall t \in, \tag{64}$$

$$X_{\mathrm{mrt}} = r_t^{dm} r_t^{di} \sum_{j\in J} \sum_{i\in I} X_{\mathrm{ijrt}} \sum_{n\in N} q_{\mathrm{in}}^{c} q_{nm}^{c} \quad \forall m \in M, \forall r \in R, \forall t \in . \tag{65}$$

Constraints (60) to (65) are balance constraints. For example, Constraint (67) expresses that the quantity of products sent from customers to collection centers is equal to or greater than the number of products sent from collection centers to reverse centers.

In Constraints (66) to (67), we have presented some equations to satisfy the demands for recovered and new products.

$$\sum_{d\in D} X_{\mathrm{idct}}^{r} \leq D_{\mathrm{ict}}^{r} \quad \forall i \in I, \forall c \in C, \forall t \in, \tag{66}$$

$$\sum_{d\in D} X_{\mathrm{idct}}^{n} \leq D_{\mathrm{ict}}^{n} \quad \forall i \in I, \forall c \in C, \forall t \in . \tag{67}$$

Another group of constraints are transportation constraints presented as follows:

$$\left(XV_{\mathrm{icjtg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{icjt}} \leq XV_{\mathrm{icjtg}} V_g \quad \forall i \in I, \forall c \in C, \forall j \in J, \forall t \in T, \forall g \in \otimes, \tag{68}$$

$$\left(XV_{\mathrm{irjtg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{ijrt}} \leq XV_{\mathrm{ijrtg}} V_g \quad \forall i \in I, \forall r \in R, \forall j \in J, \forall t \in T, \forall g \in, \tag{69}$$

$$\left(XV_{\mathrm{irftg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{irft}} \leq XV_{\mathrm{irftg}} V_g \quad \forall i \in I, \forall r \in R, \forall f \in F, \forall t \in T, \forall g \in, \tag{70}$$

$$\left(XV_{\mathrm{ifdtg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{ifdt}} \leq XV_{\mathrm{ifdtg}} V_g \quad \forall i \in I, \forall f \in F, \forall d \in D, \forall t \in T, \forall g \in, \tag{71}$$

$$\left(XV_{\mathrm{ipdtg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{ipdt}} \leq XV_{\mathrm{ipdtg}} V_g \quad \forall i \in I, \forall p \in P, \forall d \in D, \forall t \in T, \forall g \in, \tag{72}$$

$$\left(XV_{\mathrm{nrptg}} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{nrpt}} \leq XV_{\mathrm{nrptg}} V_g \quad \forall n \in N, \forall r \in R, \forall p \in P, \forall t \in T, \forall \in, \tag{73}$$

$$\left(XV_{\mathrm{idctg}}^{n} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{idct}}^{n} \leq XV_{\mathrm{idctg}}^{n} V_g \quad \forall i \in I, \forall c \in C, \forall d \in D, \forall t \in T, \forall g \in, \tag{74}$$

$$\left(XV_{\mathrm{idctg}}^{r} - 1\right) V_g \leq \sum_{i\in I} \vartheta_i X_{\mathrm{idct}}^{r} \leq XV_{\mathrm{idctg}}^{r} V_g \quad \forall i \in I, \forall c \in C, \forall d \in D, \forall t \in T, \forall g \in . \tag{75}$$

Constraints (68) to (75) express that the volume of products to be transferred should be within the range of a vehicle's capacity between n and $n-1$. Another constraint is price constraint described as follows:

$$p_i^n \leq p_i^r \quad \forall i \in I. \tag{76}$$

Constraint (76) expresses that price of recovered products is equal to or higher than the price of new products. Constraints (77) to (82) represent the degree of satisfaction in different facilities:

$$\frac{p^r - p^{r_{\min}}}{p_i^{r_{\text{did}}} - p^{r_{\min}}} \geq \mu_i^r \quad \forall i \in I, \tag{77}$$

$$\frac{p_i^{R_{\max}} - p^R}{p_i^{R_{\max}} - p_i^{R_{\text{cid}}}} \geq \mu_i^r \quad \forall i \in I, \tag{78}$$

$$\frac{p_i^n - p_i^{n_{\min}}}{p_i^{n_{\text{did}}} - p_i^{n_{\min}}} \geq \mu_i^n \quad \forall i \in I, \tag{79}$$

$$\frac{p_i^{n_{\max}} - p_i^n}{p_i^{n_{\max}} - p_i^{n_{\text{cid}}}} \geq \mu_i^n \quad \forall i \in I, \tag{80}$$

$$\frac{p_i^e - p_i^{e_{\min}}}{p_i^{e_{\text{cid}}} - p_i^{e_{\min}}} \geq \mu_i^e \quad \forall i \in I, \tag{81}$$

$$\frac{p_i^{e_{\max}} - p_i^e}{p_i^{e_{\max}} - p_i^{e_{\text{rid}}}} \geq \mu_i^e \quad \forall i \in I. \tag{82}$$

The last group of constraints is non-negativity and binary constraints (Figure 2):

$$\begin{aligned}
&\forall j \in J; \forall r \in R; \forall f \in F; \forall p \in P; \forall d \in D; \forall c \in C;\\
&\forall i \in I; \forall t \in T; Z_{jt}; Z_{rt}, Z_{ft},\\
&Z_{pt}; Z_{dt} \in \{0,1\},\\
&Y_{\text{cjt}}, Y_{\text{jrt}}, Y_{\text{rft}}, Y_{\text{rpt}}, Y_{\text{fdt}}, Y_{\text{pdt}}, Y_{\text{dct}} \in \{0,1\},\\
&X_{cj}, X_{jr}, X_{rf}, X_{rp}, X_{fd}, X_{pd}, X_{\text{mrt}}, X_{\text{npt}}, X_{dc}^r, X_{dc}^n \geq 0.
\end{aligned} \tag{83}$$

3.4. Solution Approach

(i) Epsilon constraint: the Epsilon-constraint method was used to solve multi-objective problems. The–constraint method in this study was considered according to the stance of Pirouz and Khorram [21] and recommended by Abolghasemian et al. [22] recently. Epsilon-constraint method has two main advantages. One of the advantages of the method is its reduction of the search space to find the nondominated points. Another advantage of the method is shorter run time in comparison with other methods. According to the method, we first solve the single-objective optimization problem for each goal. Next, we determine the step length. Then, we generate the suitable sets of the points, and finally, we will solve the single-objective optimization and estimate the Pareto frontier [23].

First child	1	1	0	1	1	0
Second child	1	0	0	1	0	1

Figure 2: How crossover operator works.

(ii) Nondominated sorting genetic algorithm (NSGA-II): in the present study, we applied the sorting and searching methods based on Pareto analysis in order to develop the NSGA-II algorithms. In the following section, the details of this method are described. In the searching method, a variety of solutions are first obtained. Then, the decision maker selects the most suitable solutions which should be in balance with various objectives. Nondominated sorting genetic algorithm (NSGA-II) is one of the most efficient and popular optimization algorithms. Single-objective optimization algorithms find the optimal solution according to a single objective, while no single optimal solution can be found in multi-objective problems. Therefore, we normally deal with a set of solutions named nondominated solutions. From this finite set of solutions, the suitable solutions are those with acceptable performance regarding all objectives. The stages of the developed algorithm are as follows:

(iii) Initialization and structure of chromosome: the preliminary information to initiate the proposed NSGA-II algorithm contains an initial population size, crossover possibility, and mutation possibility along with the number of iterations. The structure of the chromosome is one of the most influential parts of multi-objective optimization algorithms. Each solution set contains a set of decision variables in the problem's model. In other words, a chromosome consists of several parts, the first of which represents the Z variable which shows opened distribution centers, collection points, recovery facilities, etc. The second part of the chromosome is allocated to Y variables which show assigning customers to collection points, collection points to recovery facilities, etc. the third part of the solution shows the quantity of product transferred within X levels. The next part shows the amount of inventory transferred by each vehicle within corresponding XV levels. The final part refers to the price of new and recovered products.

(iv) Evaluation of chromosome: in this stage, various criteria are introduced in order to evaluate the solutions among the population. Fitness evaluation is to check the value of objective function while the problem's constraints are considered.

(v) Fast nondominated sorting and crowd distance: in this section, ranking based on non-dominants is compared using the concepts of dominance, dominated, and crowd distance. In fast nondominated sorting, population is ranked using the concept of dominance. Generally, in order to sort a population with size n based on nondominated levels, each solution is compared to all the other solutions in the population so the dominated or nondominated nature of that solution is determined.

(vi) Parents: since parents are necessary to produce new offspring (for each child, two parents are required in crossover operator, and a single parent is required in mutation operator, in a way that parents must be prioritized over the rest of solutions in terms of fitness), the same happens in the NSGA-II algorithm. Here, parents who go under nondominated sorting and crowd distance operations are kept, and they will go under crossover and mutation operations in the next stage according to the corresponding selection strategy.

(vii) Selection strategy: crowded tournament selection operator is used in order to select parents for crossover and mutation operators to produce new offspring. This operator compares two solutions and finally selects the best one. Two criteria are applied to evaluate these two solutions:

(1) Having the higher rank and degree of nondominance in which rank is shown as r_i

(2) Having the greater crowd distance is shown as d_i

(viii) Crossover operator: this operator is applied on Z variable. How this operator works is described in the following. First, one of Z variables is randomly selected. Then, a uniform crossover is applied to determine the value of that variable for children, in a way that a varying length string that can take binary values is generated. Then, in order to produce children, for each gene in the string, the first child takes the value assigned to the first parent in case the gene value is zero, and the child takes the value assigned to the second parent if the value is one. The case is the opposite for the second child. Finally, some solutions are generated as offspring according to parents.

The same operation happens for all the defined strings. Of course, it happens randomly for only one string every time.

(ix) Mutation operator: mutation operator is generated to change the arrangement of the genes and make slight modifications in one point of the chromosome code. When this operator is applied, a new chromosome is generated by slight modifications in the gene sequence. The main objective of using a mutation operator is to avoid putting the algorithm within the local optimum and to increase the diversity of searching solution space. In fact, the mutation operator is a simple form of local searching. The following figure is an example to show how this operator works. The initial string is associated with the first parent, and the selected genes are the second and sixth genes, respectively. As shown in Figure 3, this operator is applied to the parent string, and offspring are produced.

This operation happens to all the defined strings. Of course, it happens randomly for only one string every time.

(x) Offspring evaluation and merging with previous solutions: in the next stage, we evaluate the set of offspring produced by crossover and mutation operators. Since a certain fitness value is allocated to each child, the whole population including children and parents is merged and a population larger than the initial population (almost twice in size) is generated. When solutions are merged, better solutions among the population of parents and offspring are not lost. Needless to say, the newly generated solutions must address all the problem's constraints.

(xi) Sorting the population and selecting N chromosomes: in this section, the population members of each boundary are ranked based on crowded distance and then according to nondominated sorting. Figure 4 illustrates the mechanism of NSGA-II evolution.

After the new population is sorted and ranked, the considered stop conditions need to be checked.

4. Simulation Results

The mathematical model in Gams software was transformed into a single-objective model using the Epsilon constraint, and in a personal system with Intel Core i5 CPU and 4 GB RAM is solved using the Baron tool. Table 2 shows the results obtained from the implementation and solution of the model. In order to compare the efficiency of NSGA-II, various examples are designed in different categories and sizes to evaluate the algorithm. Table 3 shows the descriptions of each category of problems.

Since this problem has two objective functions which are in conflict, there will be a two-dimensional (2D) Pareto solution set. Figure 5 shows the 2D Pareto front plot.

In this section, the results obtained by solving certain problems are expressed in form of evaluation criteria for metaheuristic algorithms. Table 4 shows the information obtained from the NSGA-II algorithm, respectively.

The data needs to be evaluated in terms of normality in order to conduct the statistical analysis of the results of solving problems by the metaheuristic algorithm. In this test, if the P value is greater than 0.05, it indicates that the data

1	3	5	2	5	8	1	4
1	8	5	2	5	3	1	4

Figure 3: How mutation operator works.

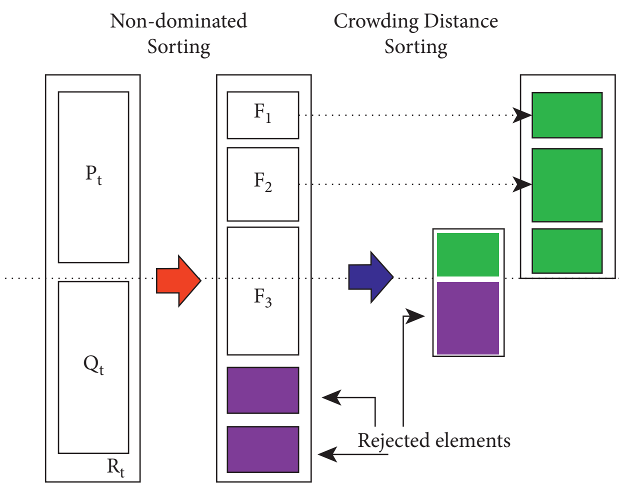

Figure 4: The process of NSGA-II evolution.

Table 2: Value of objective function.

Objective function	Customer satisfaction	Total profit	Total cost
Value	0.75	522000000	15200000

Table 3: Details of the designed problems.

Type of category	Number of problems	P, d, r, j, f	C
Small	5	[1, 3]	[4, 6]
Medium	5	[4, 5]	[6, 8]
Large	5	[5, 7]	[9, 10]

have no significant difference. Since the data obtained from the evaluation criteria have different scales, the normality test is conducted for each set of data. The results are shown in Table 5. The statistical analysis of the results is performed in the Minitab 16 Software. In this regard, the paired t-test and the Mann–Whitney test are used for statistical analysis using the results of the normality test. A confidence level (CL) of 95% is considered for the null hypothesis of zero difference between means. The results indicate the normality of data (CL = 0.05).

4.1. Model Validation. Validation step shows how the model can reflect the behavior of the real system. Model validity is accomplished through many methods that compare two outputs. In this study, absolute relative error (ARE) method was used to evaluate between the mathematical model and metaheuristic model. When ARE value is lower than 0.05 it means that the model can predict each other. Table 6 indicates the validation results. ARE value for each comparison is lower than 0.05. Therefore, both model gap is negligible.

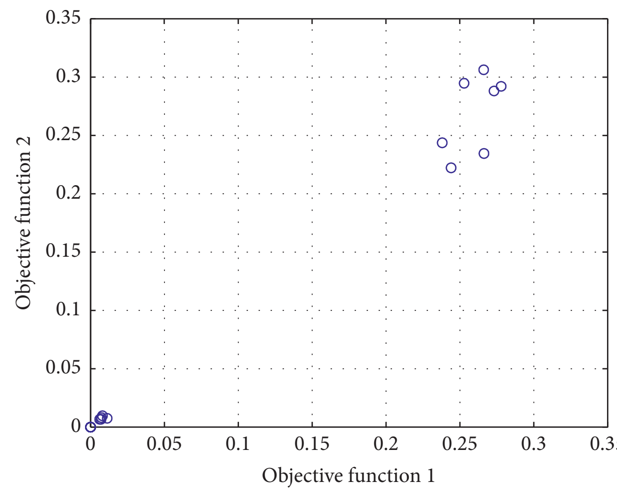

Figure 5: The Pareto set is based on two objective functions.

Table 4: Results of solution by the NSGA-II algorithm.

Problem	NPS	MID	S	D	T
1	5	0.6877	0.9856	238.06	110.35
2	6	0.620389	1.4557	244.12	150.24
3	7	0.691285	1.2589	244.42	155.04
4	7	0.630859	1.0002	243.6	174.08
5	5	0.726145	1.4678	237.8	179.91
6	9	0.612547	1.9909	359.1	255.99
7	8	0.642926	1.2774	380.36	353.88
8	8	0.720907	2.0472	369.14	394.29
9	10	0.739417	1.3449	378.11	386.12
10	7	0.6877	2.9399	385.33	376.03
11	11	0.620389	1.3593	457.6	419.21
12	13	0.691285	3.6333	455.8	483.66
13	12	0.630859	4.8656	486.1	491.14
14	14	0.726145	1.9881	492.11	479.11
15	10	0.612547	1.3486	428.62	504.83

Table 5: The results of normality test for evaluation criteria.

Criteria	P value	Result	Test
NPS	0.048	Nonparametric test	Mann–Whitney test
MID	0.01	Nonparametric test	Mann–Whitney test
S	0.15	Parametric test	Pair t-test
D	0.023	Nonparametric test	Mann–Whitney test
T	0.109	Parametric test	Pair t-test

4.2. Sensitivity Analysis. In this section, we have performed a sensitivity analysis on some important parameters such as the maximum capacity of collection, reverse, and distribution centers. For this purpose, by creating chaos in the existing value of the capacity of the considered centers, we examine the number of changes in the objective function.

Table 6: Validation.

Objective function	Output		ARE |mathematical model − NSGA|/NSGA
	Mathematical model	NSGA-II	
Customer satisfaction	0.75	0.76	0.01
Total profit	522000000	523000000	0.001
Total cost	15200000	15000000	0.01

Table 7: Sensitivity analysis.

Parameters	Current capacity			Increasing capacity (+10000)			Decreasing capacity (−10000)		
Collection center		25000			35000			15000	
Reverse center		20000			30000			10000	
Distribution center		35000			45000			25000	
Objective value	f_1^*	f_2^*	f_3^*	f_1^*	f_2^*	f_3^*	f_1^*	f_2^*	f_3^*
	0.75	522000000	15200000	0.85	545000000	160000	0.72	521000000	15100000

For this purpose, we increase and decrease the existing capacity of 10000 centers. Table 7 indicates pre-parameters for sensitivity analysis.

According to Table 7, in case of an increase of 10,000 units in the number of capacities, a significant impact on the target functions will be set. But if a reduction of 10,000 units is made, minor changes will be observed in the target functions.

5. Managerial Insights

Most organizational architectures are linear and consider the value chain model, producing and destroying the product, as a result of which the natural resources available on the planet are consumed. Hence, sustainable development guidelines are increasingly calling for the change of supply chains from linear to closed-loop models, in which circular ideals such as reuse, reconstruction and recycling are considered new. Therefore, the inclusion of existing links in supply chains has been considered by many researchers, physicians, and policymakers as an approach to improve the results of sustainability in jobs. A number of companies are looking for ways to speed up large-scale operations and move to a more closed-loop supply chain. This change requires not only innovation in product, process, and technology, but also innovation in the business model, which must consider new recycling systems to return used products. Also, it is not possible to create a supply chain link by a particular company, as this requires cooperation between different supply chain organizations and other stakeholders from similar or diverse sectors. In general, a change in an organization's business model affects the business activities of other organizations involved in their supply chain. Therefore, a systemic approach to managing the better use of materials, energy, and other valuable resources through higher recycling, reuse, and recycling rates is essential for success. However, there is limited theoretical and empirical knowledge about this phenomenon of interest. The need to meet global demand in a sustainable way that is constantly growing indicates adequate and efficient management of supply chain operations. Sustainability has been the subject of much debate in the academic literature, including the supply chain management (SCM) literature. However, global patterns of production, consumption, and trade remain dangerously unstable. If there is no change in the way supply, production, delivery, recovery, and reconstruction of products, the world will consume a lot of natural resources at its current level of consumption. An important philosophy that may help shape change is the closed-loop supply chain. This theory is increasingly recognized as a viable alternative to the economic model. Closed-loop supply chain theory is becoming an influential driving force for sustainability, both in practice and as an important potential to help organizations achieve sustainable performance success. The closed-loop supply chain has become a strategic variable for organizations even beyond the environmental aspects. There is also an important direction that increases the focus of the study in this regard and given the social and economic scenarios that affect different stakeholders, in a broader sense, as research on the method. Has shifted towards a more sustainable production system. Defining a new range of specific measures necessary for the adequate implementation of the principles of rotational economics for supply chains is the adoption of systemic innovations for them.

6. Conclusion and Future Work

This study presents the problem of supply chain planning considering product recovery processes under uncertainty in prices and using the mixed-integer nonlinear programming. In this problem, the supply chain includes customers, collection centers, return facilities, plants, recovery facilities, and distribution centers. The problem has two objective functions, the first of which seeks to maximize transaction-level satisfaction. In addition, the second objective function maximizes the profit from the supply chain. The constraints associated with the green supply chain are also considered in the problem.

The NSGA-II metaheuristic algorithm is used to solve the model. Finally, a set of small, medium, and large-scale problems are used to evaluate the performance efficiency of the algorithms. Being evaluated using the statistical methods, the results of this study indicate that in the NSGA-II algorithm, the developed model shows a good performance in terms of maximum expansion and distancing. However, no significant difference was observed in other criteria. Due to a large number of model limitations of this research, Gomez software could hardly solve the problem completely in a long time. This factor took a long time to calculate some examples. The main results of the study are as follows:

(i) The exact value of the triple objective functions is calculated

(ii) The problem is solved in small, medium, and large dimensions

(iii) The accuracy of the proposed model compared to the metaheuristic method is shown

(iv) By performing sensitivity analysis, we showed that target functions are less sensitive to reducing the capacity of centers

For further research, it is suggested to consider an appropriate robust model to deal with the uncertainty in this research and compare the results with the existing model.

Data Availability

The data are included in the article and are available.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Hindawi
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Retraction

Retracted: Environmental Regulation, Financial Resource Allocation, and Regional Green Technology Innovation Efficiency

Discrete Dynamics in Nature and Society

Received 15 August 2023; Accepted 15 August 2023; Published 16 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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Research Article

Environmental Regulation, Financial Resource Allocation, and Regional Green Technology Innovation Efficiency

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This paper empirically studies the environmental regulation, financial resource allocation, and regional green technology innovation efficiency by using provincial panel data from 2005 to 2019. The results show that the cost-input environmental regulation is negatively correlated with the efficiency of regional green technology innovation, while the government-subsidized environmental regulation is positively correlated with the efficiency of regional green technology innovation. The mechanism test shows that the cost-input environmental regulation reduces the efficiency of green technology innovation by restraining the allocation of financial resources, while the government-subsidized environmental regulation lifts the efficiency of green technology innovation by improving the allocation of financial resources. As far as different regions are concerned, the cost-input environmental regulation has a significant inhibitory effect on the eastern and central regions, while the government-subsidized environmental regulation has a significant improvement effect on the central and western regions.

1. Introduction

Since the reform and opening up, China's economy has experienced a period of rapid development driven by a crude growth model, but this has also led to problems such as environmental pollution and waste of resources, and this unsustainable and inefficient growth approach has gradually highlighted the importance of green technology innovation. Green technology innovation, as an important prerequisite for balancing China's economic growth and environmental issues, has become a major driving force for China's green economic development and transformation. Green technology innovation cannot be achieved through a single market mechanism due to the negative externalities of the ecological environment and the public goods attribute of natural resources, and needs to be led by scientific and effective environmental regulation. Therefore, it is important for the quality development of China's economy to play a positive role in environmental regulation to enhance the efficiency of green technology innovation and reduce environmental pollution and resource waste in the process of economic development. To this end, the study of the relationship between environmental regulation and the efficiency of green technology innovation is of great significance in understanding green technology innovation, solving the problem of environmental pollution in China's economic development, and continuously transforming the green economic development model.

2. Literature Review

Environmental regulation has an irreplaceable impact on green technological innovation and even economic development. Traditional economic growth theory suggests that the impact of environmental pollution and environmental policy is not significant, but in the context of sustainable development policies and environmental development, endogenous growth theory is gradually becoming a new accelerating force for economic development. Some scholars have relied on the framework of endogenous growth theory to study whether environmental policies can achieve a symbiosis between pollution control and enhancing economic development. Reference [1], while enhancing the efficiency of technological innovation through resource allocation and thus transforming economic development, has become an important way for the market to adapt to changes in environmental regulation, as well as a source and driver of green and sustainable development in China. Jie et al. have a correlation and also argue that environmental innovation is influenced by environmental regulation. Therefore, they construct a total factor productivity index for energy and carbon emissions, and in the final results show that environmental regulation has a significant positive impact on environmental innovation as well as environmental performance [2]. Zhou et al. use the Yangtze River Delta in China as the research environment to analyze the relationship between environmental regulation and innovation, and finally argue that the impact of environmental regulation on the impact of environmental regulation on innovation in the Yangtze River Delta region shows an inverted U-shape, and some policy recommendations are made to promote regional economic development [3]. Daming You et al. analyze the impact of environmental regulation on corporate eco-innovation and point out in their study that the impact of environmental regulation on corporate eco-innovation is constrained by China's fiscal system, arguing that the decentralization or otherwise of China's fiscal system can be a factor inhibiting or promoting the economic development[4].

The famous Porter Hypothesis of the 1990s argues from a dynamic perspective that reasonable environmental regulation has a compensatory effect on innovation, i.e., an appropriate intensity of environmental regulation can compensate for the cost of regulation, thus promoting technological innovation and enabling the industry in which the firm is located to gradually achieve Pareto improvements [5]. The green economy has gradually become the main direction of technological innovation adjustment, with "green" as the core and technological innovation upgraded to "green technological innovation," resulting in a number of measures of green technological innovation efficiency, among which, single indicator measures, stochastic frontier analysis (SFA), and data envelopment analysis (DEA) are the main ones. [6] Single indicator measures are based on the results of green technology innovation and use a single indicator of green technology patents to measure changes in the efficiency of green technology innovation [7]. SV Avilés-Sacoto et al. propose to use DEA to assess the efficiency of green innovation of enterprises and to analyze the relative efficiency of enterprises through inter-firm comparison [8]. Jiyoung et al. analyzed the innovation efficiency of firms in the Korean region and used DEA to assess and compare the global Malmquist productivity of firms and concluded that the innovation efficiency generated by DEA can lead to appropriate cooperation strategies between firms, which is important for the development of innovation in the market Significance [9]. Tziogkidis et al. assess the efficiency of green innovation in different countries, considering the economic environment of different countries, demonstrating a large asymmetry between innovation efficiency and sensitivity, pointing out the diversity of innovation in different countries and suggesting more informed decisions [10].

In summary, in recent years, a large number of studies on environmental regulation have pointed out its impact on environmental innovation but have not explored the specific efficiency of green innovation in depth. As for the innovation development of green innovation technology, most studies only assess the current status of green innovation efficiency through DEA but do not deeply analyze the influencing factors and mechanisms that affect the efficiency of green innovation technology. In this regard, the study starts from the analysis of the current situation of environmental regulation, proposes hypotheses on the efficiency of green technology innovation, and analyses the mechanisms affecting the efficiency of green technology innovation.

3. Empirical Analysis

3.1. Theoretical Mechanism and Research Hypothesis. Different scholars have analyzed environmental regulation and green technology innovation from different angles. Based on the static point of view, the neo-classical economics school thinks that environmental regulation can increase the production cost of enterprises and reduce the innovation ability and market competitiveness of enterprises by internalizing the negative externality of the environment, that is, "following the cost effect" [11]. From a dynamic point of view, reasonable environmental regulations will encourage enterprises to choose emission reduction technologies and equipment and improve their operating performance. The resulting "innovation compensation" may reduce or even offset the "compliance cost," thus realizing the double dividend of pollution reduction and productivity improvement [12]. However, there are many differences in the time sequence and intensity of "compliance cost" and "innovation compensation," which leads to different measurement methods of environmental regulations. Therefore, the implementation effect of environmental regulations is uncertain. With the increasing requirements of environmental quality and sustainable development, the research on environmental regulation and green technology innovation efficiency has gradually become the focus, mainly including nonlinear threshold effect and spatial spillover effect of environmental regulation [13]. At the same time, with the continuous enrichment of measurement tools and basic data, existing researches have gradually turned to the discussion of performance evaluation of green technological innovation and its influencing factors. On this basis, the spatial characteristics of green technological innovation diffusion are analyzed. With the increasingly close interregional relations, the green technology diffusion and spillover have attracted scholars' attention, and spatial factors are gradually brought into the framework of influencing factors analysis [14]. Most studies evaluate the green technology innovation ability from three dimensions including enterprises, industries, and regions [15]. Especially at the regional level, the measurement unit of green technology innovation capability is mainly based on the provincial scale. Most conclusions show that environmental regulations are closely related to the performance of regional green technology innovation, and there is certain heterogeneity in the eastern, central, and western regions [16].

Hypothesis 1. Environmental regulations will have a significant impact on the efficiency of green technology innovation.

Hypothesis 2. There are significant differences in the efficiency of green technology innovation among different regions.

Environmental regulation has a direct impact on the efficiency of green technology innovation, but it also has an indirect impact through certain factors. As environmental regulations will increase enterprises' expenditure on pollution control and investment in new technology research and development, the pursuit of green development requires financial institutions to reduce or even limit the flow of resources to highly polluting industries and enterprises in the process of resource allocation. Environmental regulations can identify enterprises with large potential output for financial institutions and optimize their resource allocation efficiency [17–19]. Therefore, reasonable environmental regulation combined with rational allocation of financial resources can achieve "win-win" between green economy and technological innovation. In addition, some studies have shown that financial deepening and financial structure optimization can promote the improvement of technical efficiency, but their effects on technological progress are inconsistent [20]. On the one hand, the promotion effect of financial resource allocation on productivity is negative, which weakens innovation and technological progress; on the other hand, the promotion effect of financial resource allocation on productivity is positive, which strengthens the improvement of resource allocation efficiency [21]. Some studies have also pointed out that enterprises may continue to produce products with high pollution and energy consumption after obtaining the allocation of financial resources, which will increase the emissions of carbon dioxide and sulfur dioxide, leading to environmental pollution and even "herding effect" [22] and thereby affect the efficiency of regional green technology innovation.

Hypothesis 3. Environmental regulation affects the efficiency of green technology innovation through the allocation of financial resources.

To sum up, under the background of China attaching increasing attention to the environment and pollution prevention and control, the development of regional green technology innovation efficiency is not unique. Environmental regulations have played an indispensable role in its evolution, and the relationship between them has become increasingly closer. As a consensus, the concept of green development is bound to be influenced by environmental regulations and other factors. Scholars have carried out relevant research from different angles, but there is little research on the relationship among them. Compared with the existing literature, the marginal contributions of this paper are as follows: (1) in terms of research data, both cost input and government subsidy are adopted to measure the level of environmental regulation to explore its influence on the efficiency of green technology innovation. At the same time, financial resource allocation is used as an intermediary variable to test the channels affecting the efficiency of green technology innovation, which can more comprehensively measure how environmental regulation plays a role in the efficiency of green technology innovation through financial resource allocation. (2) In terms of research methods, the measurement of green technology innovation efficiency in existing literature is referred. Taking industrial "three wastes" as unexpected output, Super-SBM model is used to better reflect the change of green technology innovation efficiency, and at the same time, nonlinear influence expansion analysis is used. The relationship between environmental regulation and green technology innovation efficiency and its mechanism are discussed at a deeper level, and regional analysis is made, providing references for the development of regional economies in China in a greener and more optimized direction under the background of financial resource allocation.

3.2. Model Setting. All variables are interpreted uniformly, as shown in Table 1.

To test the influence of environmental regulations on the efficiency of regional green technology innovation, this paper sets the following benchmark models by adopting the regional and temporal double-control fixed effect panel model:

$$\text{rgtie}_{\text{it}} = \alpha + \beta \text{ger}_{\text{it}} + \gamma g X_{\text{it}} + \sum_{i=1}^{30} \phi_i g \text{state\_dum}_i + \sum_{t=1}^{15} \phi_t g \text{year\_dum}_t + \mu_{\text{it}}, \tag{1}$$

rgtie in the above model, as the explained variable of this paper, is used to describe the regional green technology innovation efficiency of i province in the t year, and the specific calculation method will be explained in detail later. The explanatory variable indicates the environmental regulation level of i province in the t year. When describing the environmental regulation level, this paper considers that since the 18th National Congress, the ecological civilization construction has been raised to the level of national construction through the "five-in-one" general layout. On the one hand, the government has strengthened environmental regulation, formulated relevant laws and regulations,

Table 1: Variable interpretation.

Variable	Interpretation
X_{nt}	Control variable set
α	Regression coefficient
β	Investment proportion
er_{nt}	Core explanatory variables
γ	Weight value
n	Number of regions
t	Number of years
ϕ	Investment
state_dum_n	Enterprise investment
year_dum_t	Annual investment
μ_{nt}	Random factors
x	Investment
y	Produce
m	Number of input indicators
s	Number of output indicators
k	Production period
i	Input decision unit
r	Output decision-making unit
s_i^-	Input slack
s_r^+	Output slack
λ_j	Weight vector

strengthened environmental punishment measures, and invested a lot of money in ecological environment governance; on the other hand, the government strongly subsidizes enterprises through environmental protection expenditure, and provides support for environmental protection R&D expenses. The former can be understood as cost-input environmental regulation (lner), which is measured by the ratio of industrial pollution control investment to total industrial output value, while the latter can be understood as government-subsidized environmental regulation (environ), which is measured by the proportion of environmental protection expenditure in fiscal expenditure.

X_{it} represents the set of control variables to be included in a unified way, including R&D intensity proxy index (rdgdp) of R&D investment of *i* province in the *t* year as the share of GDP; the index ins of technology market development degree expressed by the ratio of technology market turnover and industrial added value of *i* province in the *t* year (rdgdp); industrial structure index (ins) is measured by the ratio of the added value of the second and third industries of *i* province in the first year; opening degree index (open) is measured by the proportion of foreign enterprises' import and export of *i* province to GDP in the first year; index of urbanization speed is expressed by the proportion of urbanization of *i* province in period *t* (urban).

3.3. Measurement of Efficiency of Green Technology Innovation. Referring to the measures of green technology innovation efficiency constructed by scholars in existing literature, this paper takes the industrial "three wastes" as unexpected output, and uses Super-SBM model to better reflect the change of China's green technology innovation efficiency:

$$
\begin{aligned}
&p^* = \min \frac{1 + 1/m \sum_{i=1}^{m} s_i^- / x_{ik}}{1 - 1/s1/s \sum_{r=1}^{s} s_r^+ / y_{rk}},\\
&\text{s.t.} \sum_{j=1, j\neq k}^{n} x_{ij}\lambda - s_i^- x_{ij}\,(i = 1, 2, \ldots, m),\\
&\sum_{j=1, j\neq k}^{n} y_{rj}\lambda + s_r^+ y_{rj}\,(r = 1, 2, \ldots, s),\\
&\lambda_j > 0, j = 1, 2, \ldots, n\,(j \neq k), s_i^- > 0, s_r^+ > 0,
\end{aligned}
\tag{2}
$$

wherein p^* is the efficiency value of green technology innovation; x and y are input and output elements, respectively; m and s are the number of input and output indicators, respectively; k represents the production period; i and r are the decision-making units of input and output, respectively; s_i^- and s_r^+ are the slack of input and output, respectively; and λ_j is the weight vector. When $p^* \geq 1$, the production decision-making unit is relatively effective; when $p^* < 1$, the relative ineffectiveness and efficiency loss of production decision-making units are evaluated, and the efficiency of green technology innovation are improved by optimizing input, expected output, and unexpected output.

3.4. Descriptive Statistics of Data Sources and Variables. This paper mainly uses the panel data of 30 provinces (municipalities and autonomous regions) in China from 2005 to 2019 for empirical analysis. The data mainly come from China Industrial Statistics Yearbook, China Environment Yearbook, China Statistics Yearbook, China Energy Statistics Yearbook, provincial statistical yearbooks, etc. Tibet has been excluded due to many missing data.

4. Empirical Result Analysis

4.1. Benchmark Regression Test. Table 1 reports the estimated results of environmental regulation intensity index obtained by two different measurement methods on the efficiency of regional green technology innovation. From Tables 2 and 3, it can be found that the cost-input environmental regulation plays a restraining role in influencing the efficiency of regional green technology innovation, and the conclusion is consistent from perspectives such as comprehensive efficiency, scale efficiency, and pure technical efficiency. It is not difficult to find from the regression results that the cost-controlled environmental regulations restrict the production and operation of enterprises from many aspects. The enterprises themselves are not motivated to make self-innovation and improve the production process, and their ability to reduce production pollution emissions is weak, which leads to the slow improvement and even a downward trend of their own green technology innovation efficiency.

However, the tests from (4) to (6) show that government-subsidized environmental regulations play an improving role in influencing the efficiency of regional green technology innovation, and the conclusions are consistent

Table 2: Document analysis.

Literature	Primary coverage	Problem
Jie [2]	Building total factor productivity index of energy and carbon emissions	No in-depth analysis of green innovation under environmental regulation
Zhou [3]	The relationship between environmental regulation and innovative development in the Yangtze River Delta	
Daming You [4]	The impact of China's financial system on environmental regulation	
SV Avilés-Sacoto [8]	DEA evaluation of enterprise green innovation efficiency	The influencing factors of green innovation efficiency have not been analyzed
Jiyoung [9]	Analyze the impact of enterprise innovation on the market	
Tziogkidis [10]	Discuss the efficiency of green technology innovation in different countries	
This study	Analyze the impact mechanism of environmental regulation on Green Innovation	—

Table 3: Descriptive statistics of variables.

Variable	Variable definition	Average	Standard deviation	Min	Max
TE	Comprehensive efficiency	0.673	0.153	0.498	1.312
PTE	Pure technical efficiency	0.903	0.162	0.532	1.302
SE	Scale efficiency	0.794	0.156	0.201	1.000
lner	Cost-input environmental regulation index	3.385	0.821	1.289	5.701
squ_lner	Cost-input environmental regulation index square term	12.678	5.163	1.596	31.597
environ	Government-subsidized environmental regulation index	0.054	0.031	0.012	0.173
rdgdp	R&D intensity proxy index	1.387	1.139	0.221	6.179
tel	Technical turnover intensity index	0.045	0.082	0.008	0.652
ins	Industrial structure proxy index	1.134	0.306	0.258	1.965
open	Index of openness of import and export foreign enterprises	0.147	0.203	0.034	1.689
urban	Proxy index of urbanization degree	0.607	0.182	0.215	0.763

from perspectives including comprehensive efficiency, scale efficiency, and pure technical efficiency. Seen from the regression results, the government-subsidized environmental regulations can promote the production and operation of enterprises from the perspective of subsidies or production costs, and the enterprises' self-innovation, motivation to improve the production process, cooperation with supervision, and ability to reduce production pollution emissions can be improved by cost improvement or external environment improvement, thus resulting in the improvement of their own green technology innovation efficiency. The two environmental regulation indicators are explained from two opposite directions, which verify the robustness of this conclusion.

Seen from the regression results of control variables, the control variables listed in this paper do not change the influence on the efficiency of regional green technology innovation with the measurement of relevant environmental regulation indicators. From the index of R&D innovation intensity (rdgdp), it can be seen that the influence on pure technical efficiency, comprehensive efficiency, and scale efficiency is significantly promoted. The regression result is the same as the influence of regional technology market maturity (tel) on regional green technology innovation efficiency, which indicates that the R&D intensity or technology market development degree of a region will play a very important role in promoting its green technology innovation efficiency. From the perspective of industrial structure (ins), it is found that the influence of high secondary industrial structure on regional green innovation efficiency is restrained, and the influence of industrial structure variables on regional green innovation efficiency is not very significant. At the same time, it is also concluded that both the degree of external development (open) and the degree of urbanization (urban) of a region can restrain the influence of regional green innovation efficiency.

4.2. Nonlinear Influence Expansion Analysis. From the previous analysis, it is concluded that the cost-input environmental regulation plays a restraining role in influencing the efficiency of regional green technology innovation, while the government-subsidized environmental regulation plays an improving role in influencing the efficiency of regional green technology innovation. However, further thinking will raise such questions as to whether the efficiency of green technology innovation in areas affected by environmental regulations is nonlinear, whether there is an inflection point or threshold, and whether relevant conclusions will change after crossing the inflection point. Therefore, this paper introduces the quadratic terms of two kinds of environmental regulations into the model to explore whether this nonlinear influence exists.

$$\begin{aligned}\mathrm{rgtie}_{\mathrm{it}} &= \alpha + \beta_1 \mathrm{ger}_{\mathrm{it}} + \beta_2 g \mathrm{squ\_}er_{\mathrm{it}} + \gamma g X_{\mathrm{it}} \\ &\quad + \sum_{i=1}^{30} \phi_i g \mathrm{state\_dum}_i + \sum_{t=1}^{15} \phi_t g \mathrm{year\_dum}_t + \mu_{\mathrm{it}}.\end{aligned} \tag{3}$$

The empirical results show that environmental regulations have a nonlinear influence on the efficiency of regional green technology innovation. Specifically, cost-input environmental regulation has a positive U-shaped impact on the efficiency of regional green technology innovation; the government-subsidized environmental regulation has an inverted U-shaped impact on the efficiency of regional green technology innovation. From the further analysis of relevant inflection points, we can calculate that 95% of the samples are on the left side of the inflection point. That is, the cost-input environmental regulation is in a state of inhibiting the efficiency of regional green technology innovation, while the government-subsidized environmental regulation is in a state of "climbing" improvement, which just confirms the regression results of the benchmark model.

4.3. Analysis of Regional Heterogeneity. This paper takes into account the fact that the control indicators of environmental regulation in the benchmark model have the same influence on regional green innovation efficiency measured by scale efficiency, pure technical efficiency, and comprehensive efficiency. In further analysis, by splitting the samples, we consider what changes will the environmental regulations bring to the efficiency of regional green innovation in different regions? From the regression results in Tables 6 and 7, we can see that the cost-input environmental regulation has obvious inhibitory effect on the eastern and central regions, and its positive U-shaped influence in the eastern and central regions has not changed due to subsamples. Government-subsidized environmental regulation has obvious improvement effect on the central and western regions, and its inverted U-shaped influence on the efficiency of green innovation in the central and western regions has not changed.

4.4. Analysis of Influence Mechanism. Through the previous analysis, it is found that the influence of environmental regulation on the efficiency of regional green technology innovation varies with different measurement methods of environmental regulation. However, we cannot help asking, what is the path of environmental regulation's influence on the efficiency of regional green technology innovation? What role does this financial resource allocation play, and whether environmental regulations will affect the regional financial resource allocation, thus affecting the local green technology innovation efficiency? Next, this paper introduces the allocation of financial resources into the model through the intermediary model formulas (4)–(6), and uses the existing literature to measure the allocation of regional financial resources for reference. Besides, it standardizes the variables of regional financial resources allocation. To further explore the impact mechanism of environmental regulation on regional green technology innovation efficiency, we firstly construct formula (4), aiming to investigate the overall influence of environmental regulations on the efficiency of regional green technology innovation, which is the same as the benchmark. Secondly, we construct formula (5), aiming to investigate whether environmental regulations have an impact on the allocation of regional financial resources. Finally, on the basis of formula (4), the intermediary variable is introduced into the model to test whether environmental regulation affects the efficiency of regional green technology innovation by influencing the allocation of financial resources, and formula (6) is constructed at the same time.

$$\text{rgtie}_{\text{it}} = \alpha + \beta \text{ger}_{\text{it}} + \gamma g X_{\text{it}} + \sum_{i=1}^{30} \phi_i g \text{state\_dum}_i + \sum_{t=1}^{15} \phi_t g \text{year\_dum}_t + \mu_{\text{it}}, \tag{4}$$

$$\text{finadd\_sta}_{\text{it}} = \alpha + \beta \text{ger}_{\text{it}} + \gamma g X_{\text{it}} + \sum_{i=1}^{30} \phi_i g \text{state\_dum}_i + \sum_{t=1}^{15} \phi_t g \text{year\_dum}_t + \mu_{\text{it}}, \tag{5}$$

$$\text{rgtie}_{\text{it}} = \alpha + \beta \text{ger}_{\text{it}} + \varphi g \text{finadd\_sta}_{\text{it}} + \gamma g X_{\text{it}} + \sum_{i=1}^{30} \phi_i g \text{state\_dum}_i + \sum_{t=1}^{15} \phi_t g \text{year\_dum}_t + \mu_{\text{it}}. \tag{6}$$

From the regression results of the intermediary mechanism test in Table 8, we can see that the improvement of the allocation of financial resources in a region can significantly promote the efficiency of green technology innovation. However, the cost-input environmental regulation plays a certain role in restraining the local financial resource allocation, while the government-subsidized environmental regulation, on the contrary, improves the local financial resource allocation. This also explains why the cost-input environmental regulation can restrain the local green technology innovation efficiency, while the government-subsidized environmental regulation is easy to improve the local green technology innovation efficiency. By observing the significance and symbols of related variables, we can find that some intermediary effects of environmental regulations, through the allocation of financial resources, affect the efficiency of local green technology innovation.

4.5. Robustness and Endogenous Test. Table 9 (1) and (2) are listed as robustness tests, and the regression is conducted after removing 5% outliers before and after the core explanatory variables of cost-input environmental regulation (lner) and government-subsided environmental regulation (environ), and the results are consistent with the benchmark model test. (3) and (4) are listed as endogenous tests, and the lag period of the explained variable (LTE) is added to the original model for systematic GMM test. The results show that, after correcting the endogenous problems of the model, the cost-input environmental regulation inhibits the regional green technology innovation efficiency, while the government-subsidized environmental regulation promotes the regional green technology innovation efficiency.

4.6. Discussion. The development of green technological innovation is a common trend in current international development, and in the development of innovation in

Table 4: Estimated results of benchmark model.

Variables	Cost-input environmental regulation			Government-subsidized environmental regulation		
	(1) TE	(2) PTE	(3) SE	(4) TE	(5) PTE	(6) SE
lner	−0.023 *** (−2.309)	−0.239 ** (−1.990)	−0.012 * (−1.749)			
environ				1.177 *** (2.785)	3.252 ** (2.458)	0.115 *** (3.397)
rdgdp	0.075 *** (2.899)	0.077 ** (2.255)	0.037 ** (2.088)	0.087 *** (3.328)	0.102 ** (2.331)	0.036 ** (2.013)
tel	0.727 *** (5.067)	0.375 *** (3.225)	0.090 * (1.914)	0.700 *** (4.869)	0.447 *** (4.028)	0.105 ** (2.056)
ins	−0.071 ** (−2.450)	−0.249 (−0.733)	−0.008 (−0.427)	−0.023 ** (−2.667)	−0.156 (−0.443)	−0.002 (−0.114)
open	−0.092 * (−1.934)	−0.052 (−0.094)	−0.026 (−0.818)	−0.105 ** (−2.251)	−0.223 (−0.407)	−0.017 (−0.553)
urban	−0.593 *** (−4.247)	−3.870 ** (−2.389)	−0.089 (−0.929)	−0.110 (−0.598)	−3.691 * (−1.716)	−0.063 (−0.498)
Constant	1.222 *** (11.966)	3.931 *** (3.318)	1.025 *** (14.626)	0.806 *** (6.887)	3.006 ** (2.197)	0.966 *** (11.940)
Observed value	450	450	450	450	450	450
R^2	0.529	0.319	0.247	0.551	0.311	0.240
Regional quantity	30	30	30	30	30	30
Control year	YES	YES	YES	YES	YES	YES
Control area	YES	YES	YES	YES	YES	YES

Note. ***, **, and * represent being significant at the level of 1%, 5%, and 10%, respectively. *t* value is shown in brackets, same as that in Tables 3 to Table 7.

Table 5: Estimated results of non-linear effects.

Variables	Cost-input environmental regulation			Government-subsidized environmental regulation		
	(1) TE	(2) PTE	(3) SE	(4) TE	(5) PTE	(6) SE
lner	−0.041 *** (−3.691)	−0.197 *** (−3.280)	−0.058 * (−1.809)			
squ_lner	0.004 *** (3.301)	0.024 *** (3.630)	0.010 * (1.734)			
environ				4.189 *** (3.791)	3.077 *** (3.082)	3.195 *** (4.256)
squ_environ				−22.340 *** (−2.945)	−22.113 *** (−3.358)	−24.560 *** (−4.766)
rdgdp	0.076 *** (2.908)	0.105 *** (3.344)	0.032 * (1.815)	0.090 *** (3.469)	0.098 *** (3.317)	0.039 ** (2.246)
tel	0.728 *** (5.067)	0.399 ** (2.240)	0.086 *** (3.876)	0.635 *** (4.410)	0.140 *** (3.082)	0.034 *** (3.348)
ins	−0.072 ** (−2.457)	−0.241 (−0.708)	−0.007 (−0.362)	−0.024 (−0.806)	−0.158 (−0.446)	−0.003 (−0.169)
open	−0.093 * (−1.949)	−0.027 (−0.049)	−0.030 (−0.940)	−0.100 ** (−2.157)	−0.215 ** (−2.392)	−0.023 ** (−2.750)
urban	−0.590 *** (−4.210)	−3.943 ** (-2.426)	−0.101 (−1.054)	−0.024 (−0.128)	−3.498 (−1.576)	-0.084 (-0.660)
Constant	1.252 *** (8.803)	3.209 * (1.946)	0.908 *** (9.336)	0.671 *** (5.382)	2.812 * (1.909)	0.817 *** (9.641)
Observed value	450	450	450	450	450	450
R^2	0.559	0.330	0.241	0.590	0.333	0.210
Regional quantity	30	30	30	30	30	30
Control year	YES	YES	YES	YES	YES	YES
Control area	YES	YES	YES	YES	YES	YES

China, green development has gradually become an important goal for market development. According to existing studies, the allocation of financial resources under environmental regulation has a certain influence on the development of green technological innovation, but the correlation between environmental regulation and green

Table 6: Estimated results of regional heterogeneity of cost-input environmental regulation.

Variables	Eastern region		Central region		Western region	
	(1) TE	(2) TE	(3) TE	(4) TE	(5) TE	(6) TE
lner	−0.027 * (−1.777)	−0.110 * (−1.853)	−0.041 ** (−2.559)	−0.076 ** (−2.642)	−0.016 (−1.011)	−0.018 (−0.170)
squ_lner		0.012 * (1.844)		0.018 * (1.717)		0.001 (0.025)
rdgdp	0.128 *** (2.640)	0.134 *** (2.709)	0.038 (0.802)	0.036 (0.753)	0.003 (0.056)	0.003 (0.053)
tel	0.795 *** (3.987)	0.803 *** (4.012)	0.791 (1.408)	0.796 (1.422)	1.145 * (1.945)	1.147 * (1.915)
ins	−0.188 * (−1.876)	−0.186 * (−1.854)	−0.038 (−1.077)	−0.040 (−1.121)	−0.034 (−0.780)	−0.034 (−0.777)
open	−0.073 (−0.973)	−0.079 (−1.040)	0.820 ** (2.138)	0.811 ** (2.123)	−0.204 (−0.473)	−0.209 (−0.440)
urban	−0.251 (−0.618)	−0.202 (−0.486)	−0.951 *** (−3.361)	−1.008 *** (−3.532)	−0.796 *** (−3.479)	−0.797 *** (−3.419)
Constant	1.440 *** (3.929)	1.549 *** (3.829)	1.243 *** (7.291)	1.093 *** (5.359)	1.016 *** (7.622)	1.022 *** (3.894)
Observed value	165	165	120	120	165	165
R^2	0.340	0.342	0.397	0.406	0.238	0.238
Regional quantity	11	11	8	8	11	11
Control year	YES	YES	YES	YES	YES	YES
Control area	YES	YES	YES	YES	YES	YES

Table 7: Estimated results of regional heterogeneity of government-subsidized environmental regulations.

Variables	Eastern region		Central region		Western region	
	(1) TE	(2) TE	(3) TE	(4) TE	(5) TE	(6) TE
environ	2.875 (1.236)	5.728 (1.394)	1.334 ** (2.250)	6.971 *** (3.600)	0.396 * (1.711)	2.188 ** (2.233)
squ_environ		−8.112 (−0.731)		−52.526 *** (−3.046)		−11.187 ** (−2.064)
rdgdp	0.150 *** (3.098)	0.157 *** (3.173)	0.062 (1.318)	0.060 (1.331)	0.006 (0.094)	0.002 (0.003)
tel	0.686 *** (3.326)	0.713 *** (3.398)	0.669 (1.171)	0.870 (1.568)	1.105 * (1.879)	0.986 * (1.746)
ins	−0.127 (−1.312)	−0.129 (−1.330)	0.014 (0.451)	0.027 (0.891)	−0.013 (−0.266)	−0.015 (−0.313)
open	−0.112 (−1.553)	−0.121 (−1.651)	0.632 * (1.797)	0.668 * (1.751)	−0.152 (−0.356)	−0.134 (−0.315)
urban	−0.307 (−0.731)	−0.267 (−0.630)	−0.302 (−1.097)	−0.153 (−0.569)	−0.587 * (−1.972)	−0.423 * (−1.863)
Constant	0.913 ** (2.577)	0.912 ** (2.570)	0.713 *** (5.303)	0.495 *** (3.353)	0.818 *** (5.014)	0.705 *** (3.623)
Observed value	165	165	120	120	165	165
R^2	0.257	0.260	0.589	0.618	0.435	0.442
Regional quantity	11	11	8	8	11	11
Control year	YES	YES	YES	YES	YES	YES
Control area	YES	YES	YES	YES	YES	YES

technological innovation as understood by most studies is not comprehensive, so the study uses empirical analysis to further explore the influence mechanism of environmental regulation on green technological innovation.

From the baseline regression test, it can be seen that the weak motivation of enterprises to innovate themselves and improve their production processes, as well as their weak ability to cooperate with regulation and reduce production pollution emissions, are the main reasons for their lack of green innovation capacity. An extended analysis of the nonlinear effects shows that environmental regulations have a nonlinear impact on the efficiency of regional green technology innovation. Specifically, cost-input environmental regulations have a positive U-shaped effect on the efficiency of regional green technology innovation, while government-subsidized environmental regulations have an inverted U-shaped effect on the efficiency of regional green technology innovation. The results of the nonlinear impact analysis

Table 8: Estimated results of intermediary mechanism test.

Variables	Cost-input environmental regulation			Government-subsidized environmental regulation		
	(1) TE	(2) finadd_sta	(3) TE	(4) TE	(5) finadd_sta	(6) TE
lner	−0.023** (−2.309)	−0.001** (−2.067)	−0.023** (−2.309)			
environ				1.177*** (2.785)	0.632*** (2.885)	1.160*** (2.714)
finadd_sta			0.063** (2.678)			0.027** (2.284)
rdgdp	0.075*** (2.899)	0.132*** (9.692)	0.084*** (−2.907)	0.087*** (3.328)	0.126*** (9.225)	0.091*** (3.145)
tel	0.727*** (5.067)	0.528*** (7.052)	0.693*** (4.563)	0.700*** (4.869)	0.502*** (6.746)	0.686*** (4.527)
ins	−0.071** (−2.450)	−0.124*** (−8.139)	−0.063** (−2.021)	−0.023** (−2.667)	−0.108*** (−6.893)	−0.020** (−2.635)
open	−0.092* (−1.934)	−0.219*** (−8.834)	−0.078 (−1.503)	−0.105** (−2.251)	−0.217*** (−8.949)	−0.099* (−1.944)
urban	−0.593*** (−4.247)	0.570*** (7.820)	−0.629*** (−4.205)	−0.110 (−0.598)	0.764*** (8.006)	−0.130 (−0.660)
Constant	1.222*** (11.966)	−0.184*** (−3.456)	1.234*** (11.903)	0.806*** (6.887)	−0.317*** (−5.235)	0.815*** (6.733)
Observed value	450	450	450	450	450	450
R^2	0.529	0.802	0.541	0.551	0.806	0.592
Regional quantity	30	30	30	30	30	30
Control year	YES	YES	YES	YES	YES	YES
Control area	YES	YES	YES	YES	YES	YES

Table 9: Test results of robustness and endogeneity.

Variables	(1) TE	(2) TE	(3) TE	(4) TE
lner	−0.033*** (−2.725)		−0.023*** (−0.440)	
environ		1.136*** (2.589)		1.587** (2.501)
rdgdp	0.062** (2.354)	0.078*** (2.891)	0.070** (1.964)	0.085 (0.699)
tel	0.679*** (4.770)	0.663*** (4.625)	0.889*** (2.923)	0.662* (1.852)
ins	−0.078*** (−2.634)	−0.029 (−0.940)	1.148** (2.151)	1.053** (2.106)
open	−0.082* (−1.701)	−0.103** (−2.163)	0.250** (2.161)	0.271** (2.245)
urban	−0.644*** (−4.496)	−0.154 (−0.815)	−1.016* (−1.652)	−0.292*** (−7.010)
L.TE			−0.200*** (−4.698)	−0.358*** (−5.289)
Constant	1.266*** (11.90)	0.823*** (6.934)	—	—
Observed value	405	405	390	390
R^2	0.154	0.152	—	—
Regional quantity	30	30	30	30
Control year	YES	YES	YES	YES
Control area	YES	YES	YES	YES

corroborate the regression results of the benchmark model and meet the relevant findings of previous studies [23].

From a heterogeneity perspective, cost-input-based environmental regulation has a significant inhibitory effect on the eastern and central regions, and government-subsidized environmental regulation, an improvement in the central and western regions, while the inverted U-shaped effect of regional green innovation efficiency does not change as a result of subsampling. The test for the mediating mechanism found that improvements in regional financial resource allocation significantly contributed to the efficiency of regional green technology innovation. The cost-input type of environmental regulation has a dampening effect on local financial resource allocation, while government-subsidized environmental regulation, on the contrary, improves local financial resource allocation, in line with the results of previous studies [24].

5. Conclusions and Policy Implications

This paper uses panel data from 30 Chinese provinces (cities and autonomous regions) from 2005 to 2019 to conduct an empirical analysis, and uses a mediating effects model to discuss the relationship between environmental regulation, financial resource allocation, and green technology innovation efficiency using financial resource allocation as a mediating variable. The empirical results show that there is a significant correlation between the intensity of environmental regulation and green technology innovation efficiency. As the intensity of environmental regulation increases, the production cost of market enterprises increases, and the green technology innovation efficiency tends to decrease and then increase.

In the pursuit of economic growth, China has come to realize that administrative measures such as environmental regulation can reduce the "negative externalities" of environmental pollution. In order to better coordinate the relationship between environmental regulation and green technological innovation, this paper proposes the following recommendations: firstly, we should give full play to the role of environmental regulation; strengthen the awareness of ecological protection; effectively improve the scientific concept of development; actively abandon high energy consumption, high pollution, and low value-added projects; continue technological innovation; and accelerate the transformation to strategic emerging industries and tertiary industries. Secondly, we should focus on financial resource allocation reform, actively implement and improve financial policies related to green development, promote green technology innovation, make financial resource allocation better match with environmental regulations, and further match a series of related green production and operation activities of enterprises. Finally, we should continue to promote the development of a coordinated regional economy and an inclusive economy; improve the efficiency of regional green technology innovation; strive to create a green, low-carbon and circular economic system; and scientifically handle the relationship between environmental protection and economic development.

Data Availability

No data were used to support the findings of the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Coupling and Coordination of the Regional Economy, Tourism Industry, and Exhibition Industry of China's Provinces

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There is a close correlation between regional economy, tourism, and exhibition industry. By constructing a system of evaluation indicators for the regional economy, tourism industry, and exhibition industry, the coupled coordination degree model was used to calculate the degree of synergy of the regional economy, tourism industry, and exhibition industry in China from 2013 to 2019. In addition, the influencing factors of the degree of synergy were analyzed by gray correlation analysis. As shown by the results, the comprehensive development scores of regional economy, tourism industry, and exhibition industry show an overall growth trend, while the development level index presents a spatial distribution pattern of decreasing gradient from coastal area to inland in space. Apart from that, the integration and development of regional economy, tourism industry, and exhibition industry show a continuous coordinated and benign development. On a national scale, the degree of integration of the regional economy-tourism industry-exhibition industry in China has gradually developed and improved from bare coordination to good coordination. Besides, the degree of coupling and coordination of regional economy-tourism-exhibition industry varies greatly among provinces. Moreover, all the indexes have a strong impact on the coupling and coordination degree of the regional economy-tourism industry-exhibition industry. Compared with the exhibition industry system, the economic system and tourism system have a stronger impact on the coupling and coordination degree of the regional economy-tourism industry-exhibition industry.

1. Introduction

Regional economy is not only the foundation and prerequisite for the development of tourism and exhibition industry but also the guarantee for the development of the other two industries [1, 2]. The tourism industry, as a comprehensive industry, involves several industries and sectors and exerts a pulling effect on economic development [3, 4]. At present, the exhibition industry is gradually developing into a hot spot that drives regional and global economic development [5]. This paper has discussed the coupling and coordination of the economy, tourism, and exhibition industry, the purpose of which is to promote the synergistic development of them, so that the structure of the economy, tourism, and exhibition system can be more reasonable and powerful, and the effect of "$1+1>2$" can be achieved to better promote economic growth.

The current research focuses on the relationship between them. Firstly, the relationship between the economy and tourism is focused [1, 6, 7]. Some researchers found that tourism development has a significantly positive impact on economic growth in China [7]. By using a coupling and coordination model, some scholars studied the coordination between the economy and tourism, and demonstrated a significant interaction between the two [1, 6]. Secondly, the relationship between the economy and exhibition industry is focused [8, 9]. Dwyer et al. measured the impact of exhibition activities on the economy of the place where they were held, and found that the exhibition activities could positively affect the regional economy [8]. As pointed out by Luo, the exhibition industry can promote the development of the economy through spatial econometric analysis [9]. Thirdly, the relationship between tourism and the exhibition industry is focused [10]. Yin and Yang studied the coordination relationship between tourism and exhibition industry using the coupling and coordination model. Then, the results proved that there is a significant coupling relationship between them [10]. In summary, fewer studies have been conducted to investigate the coupling relationship between regional economy, tourism, and exhibition industry for quantitative analysis. The contributions of this study are as follows: (1) first, this paper integrates the coupling and coordination model to analyze the coupling relationship between economy, tourism, and exhibition industry in 29 provinces in China and explore the characteristics of their spatial evolution patterns. (2) Second, the method of gray correlation is used to analyze the factors that affect the coupling coordination degree.

2. Data and Methods

2.1. Index Construction. Indictors of regional economy are based on Ref. [2, 11–14], indicators of tourism industry are based on Ref. [15–18], and indicators of the exhibition industry are based on Ref. [19, 20]. Besides, the development level of the regional economy is measured from the perspectives of economic quality, economic structure, and economic sustainability. Additionally, economic quality is measured by two indexes of GDP per capita and per capita disposable income. Meanwhile, the economic structure is measured by two perspectives of industry scale and industry efficiency, and economic sustainability is measured by two indexes of fiscal revenue and GDP growth rate. Apart from that, the development level of the exhibition and tourism industry is measured from two perspectives of industry scale and industry efficiency. What's more, the scale of the tourism industry is measured by two indexes of domestic tourist income and international tourist income. Furthermore, the effect of the tourism industry is measured by three indexes of the number of travel agencies, the number of A-grade scenic spots, and the number of starred hotels. The scale of the exhibition industry is measured by the number of exhibitions and the exhibition area. At the same time, the efficiency of exhibition industry is measured by two indexes: the number of professional exhibitions and the area of professional exhibition halls (see the index system in 1).

2.2. Research Methods and Measurement Models

2.2.1. Entropy Evaluation Method. The entropy evaluation method is a comprehensive evaluation method that objectively assigns weights to each index by analyzing the degree of correlation between indexes and the amount of information provided based on the original information of the objective environment. To a certain extent, it can reduce the bias caused by the subjective method and improve the scientificity of the evaluation results [21]. In order to avoid the impact of different dimensions on the calculation results, the data of the evaluation indexes of the regional economy-tourism industry-exhibition industry system are nondimensional by using the range standardization method before the use of the entropy evaluation weight method. Beyond that, the calculation formula can be expressed as follows.

2.2.2. Comprehensive Development Index. The integrated evaluation function of the regional economic-tourism industry-exhibition system is specified by

$$\mathrm{Xi} = \sum_{i=1}^{n} w_i x_i^*, \mathrm{i} = 1, 2, 3. \quad (1)$$

2.2.3. Coupling and Coordination Degree Model. Although the coupling degree index C indicates the tightness of the coupling of the three systems, it cannot reflect the actual interaction and coordination degree of the three systems. Therefore, the coupling and coordination degree index D should be introduced to measure the degree of interaction of the three systems. To be specific, the regional economy-tourism industry-exhibition industry system coupling model has been constructed with the following formula:

$$T = \alpha u_1 + \beta u_2 + \lambda u_3, \quad (2)$$

$$D = \sqrt{C \cdot T}. \quad (3)$$

Here, D represents the coupling and coordination index, which indicates the degree of coordination and interaction of the systems. In addition, T represents the comprehensive evaluation index of the three systems, which reflects the overall effectiveness of the three systems. Apart from that, α, β, and γ represent the weights to be determined, $\alpha + \beta + \gamma = 1$. It is generally considered that the three systems are equally important. Thus, the values of α, β, and γ are the same, and all values are taken as 1/3 in this paper [22]. In this research, the "ten-point method" evaluation grade of coupling coordination degree is adopted [23].

2.3. Gray Correlation Model. Gray correlation analysis, as a part of gray system theory, is effective in analyzing the degree of association of various factors of a system. It has been applied in multiple fields of disciplinary research and is widely adopted by scholars. Indeed, the gray correlation analysis method is not affected by the number of samples or the regularity of the samples. The basic idea is to judge whether the connection is as close as possible based on the similarity of the geometric shape of the sequence curves. Generally speaking, the closer the curves are, the greater the correlation between the corresponding sequences, and vice versa. Therefore, this method can be used to measure the relative importance of the impact of each factor on the coordination degree of the system, so as to guide the determination of the relative key influencing factors [24]. In this paper, this method is used to analyze the degree of impact of each index in the regional economy-tourism industry-exhibition industry coordination evaluation index system on the coupling and coordination degree. Beyond that, the correlation value reflects the extent to which the change in coordination is influenced by a factor. The calculation process of gray correlation mainly consists of three steps: initialization of the original data, calculation of the absolute difference between the comparison series and the reference series, calculation of the gray correlation degree, and the ranking of the correlation order:

(1) Initialization of original data

Given that there are some differences in the meaning, content, and value criteria of each index, the data tend to have different scales, which are not favorable to uniform comparison. In order to make it comparable, the application of the gray correlation method generally requires the nondimensional processing of the data as well as the elimination of the individual valid factors of each datum. In that way, it is a standardized order of magnitude nondimensional data under a unified measurement scale, to facilitate the comparative analysis of each index. Therefore, the influencing factor data and the reference sequence need to be nondimensionalized prior to the subsequent analysis. In this paper, the data are normalized through the equalization process.

$$x_i'(k) = \frac{x_i(k)}{\overline{x_i}}. \quad (4)$$

(2) Calculation of the absolute difference between the comparison sequence and the reference sequence.

$$\Delta_i(k) = \left|x_0'(k) - x_i'(k)\right|. \quad (5)$$

The comparison sequence is a sequence of data consisting of factors that influence the behavior of the system, which is constructed using the values taken from the evaluation indexes of each evaluated object.

(3) Gray coefficient and gray correlation degree of the index system

The gray correlation coefficient refers to the expression of correlation in gray theory. In essence, correlation denotes the degree of difference in geometry between the curves. Therefore, the size of the difference between the curves can be adopted as the dimension to measure the degree of correlation. In the gray correlation analysis method, the correlation coefficient refers to the geometric distance between the reference sequence and the comparison sequence at each point in time. The larger the value is, the greater the degree of correlation between the two index series on the corresponding indexes. Its calculation formula can be expressed as follows:

$$\gamma(x_0(k), x_i(k)) = \frac{\min_j \min_k \Delta_i(k)\xi + \min_j \min_k}{\Delta_i(k) + \xi \min_j \min_k \Delta_i(k)}. \quad (6)$$

Among them, D represents a constant, which is usually taken as 0.5 and is 0.5 in this paper.

Since the correlation coefficient is the degree of correlation between the reference sequence and the comparison sequence, as well as the degree of correlation at different points in time, there is more than one correlation coefficient and the distribution is scattered. Thus, making a uniform comparison is impossible. The gray correlation degree is the value obtained by pooling these correlation coefficients via certain methods, which can reflect the degree of correlation between the reference sequence and other indexes in general. In general, the larger the value of gray correlation degree, the stronger the correlation.

The formula for calculating the comprehensive gray correlation degree can be expressed as follows:

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} \gamma(x_0(k), x_i(k)). \quad (7)$$

2.4. Data Sources. The data used in this paper include both socio-economic statistics and basic geographic map data. Specifically, 29 provinces (districts and cities) in 2013 are selected as the benchmark, in which Tianjing, Tibet, Taiwan Province, Hong Kong Special Administrative Region, and Macao Special Administrative Region are excluded. In addition, Tibet and Tianjin are not included due to missing data. Apart from that, the data of GDP per capita, per capita disposable income, the proportion of the secondary industry, the proportion of the tertiary industry, fiscal revenue, and GDP growth rate of each place are obtained from *China Statistical Yearbook* and CSMAR from 2013 to 2019. Moreover, the data on domestic tourist revenue, international tourist revenue, number of travel agencies, number of A-grade scenic spots, and number of starred hotels are mainly acquired from *China Tourism Statistical Yearbook* from 2013 to 2019. In addition, the data on the number of exhibitions, exhibition area, number of professional exhibition venues, and area of professional exhibition venues are mainly obtained from the *China Exhibition Data Statistical Report* from 2013 to 2019 (Table 1).

2.5. Analysis of the Results

2.5.1. Analysis of the Comprehensive Development Level Measurement of Regional Economy, Tourism Industry, and Exhibition Industry. The regional economic development level indexes in 2013, 2015, 2017, and 2019 are divided into five levels of low, relatively low, medium, relatively high, and high by the natural break method of ArcGIS software and then spatially visualized (Figure 1). Obviously, the development pattern of the four periods does not change greatly, and the development pattern as a whole presents a spatial distribution pattern of decreasing gradient from the coast to the inland. As shown in Figure 1, in six years, a province upgrades, and Hubei rises from medium to relatively high. Besides, 8 provinces downgrade. Shaanxi and Chongqing decrease from relatively high to medium; Inner Mongolia and Liaoning decrease from higher to relatively low; Qinghai, Sichuan, and Yunnan reduce from medium to relatively low; and Gansu and Jilin decrease from relatively low to low. Additionally, Shanghai, Beijing, Jiangsu, Zhejiang, and Guangdong do not change and remain high, and Xinjiang and Heilongjiang are low without changes.

Table 1: The index system.

Subsystem	Primary indexes	Secondary indexes
Regional economy	Economic quality	GDP per capita
		Per capita disposable income
	Economic structure	The proportion of secondary industry
		The proportion of tertiary industry
	Economic sustainability	Fiscal revenue
		GDP growth rate
Tourism industry	Industry scale	Number of travel agencies
		Number of A-grade scenic spots
		Number of starred hotels
	Industry efficiency	Domestic tourist income
		International tourist income
Exhibition industry	Industry scale	Number of exhibitions
		Exhibition area
	Industry efficiency	Number of professional venues
		Area of professional venues

The tourism development level indexes in 2013, 2015, 2017, and 2019 are divided into five grades, low, relatively low, medium, relatively high, and high by the natural break method of ArcGIS software, and then visualized spatially (Figure 2). It is obvious that six provinces have increased in rank over the last six years, Qinghai from low to high, Sichuan and Yunnan from medium to relatively high, Guangxi from relatively low to relatively high, and Guizhou and Jiangxi from relatively low to medium. However, one province is downgraded, with Liaoning declining from relatively high to medium. Other provinces are more stable, and the eastern coastal provinces of Shandong, Jiangsu, Zhejiang, and Guangdong have been in the high value area. Nonetheless, Gansu, Xinjiang, Heilongjiang, and Jilin have been in the low level, which are poorly located and far away from the main customer markets.

The development level indexes of the exhibition industry in 2013, 2015, 2017, and 2019 are divided into 5 levels, low, relatively low, medium, relatively high, and high by the natural break method of ArcGIS software, and then visualized spatially (Figure 3). Obviously, 5 provinces are upgraded in 6 years, with Henan from medium to relatively high, Hubei and Hunan from relatively low to medium, Yunnan from low to medium, and Jiangxi from low to relatively low. In addition, 2 provinces are downgraded, with Beijing from relatively high to medium and Shaanxi from medium to relatively low. Furthermore, Shandong, Jiangsu, Guangdong, and Shanghai have been in the highest grade without changes, with more frequent economic activities in these areas and more stable development of the exhibition industry. Apart from that, Gansu, Xinjiang, and Qinghai have been in the lowest grade, with inactive economic activities and underdeveloped exhibition industry development.

2.6. General Dynamics of the Coupling and Coordination of Regional Economy-Tourism Industry-Exhibition Industry. This study measures the level of coupling and coordination development of the national economy, tourism industry, and exhibition industry from 2013 to 2019 (see the specific results in Table 2 and Figure 4). The coupling and coordination degree of China's economy, tourism industry, and exhibition industry has changed significantly from 2013 to 2019 (from 0.508 in 2014 to 0.850 in 2019). The coordination level of the economy, tourism industry, and exhibition industry tends to be benign, and the degree of coordinated development is gradually improved.

In order to better analyze the spatially differentiated characteristics of the coupling and coordination degree, this paper studies the coupling and coordination degree of the levels of the regional economy, tourism industry, and exhibition industry in 2013, 2015, 2017, and 2019, respectively. In 2013, in the eastern region, Guangdong has the highest coupling and coordination degree, reaching the intermediate coordination stage. Beyond that, Shandong, Zhejiang, and Jiangsu are at the initial coordination stage. Liaoning in the Northeast is at the bare coordination stage, while Heilongjiang and Jilin are at the mild imbalance stage. At the same time, Anhui, Henan, and Hubei in the central region are on the verge of the imbalance stage, while Shanxi, Hunan, and Jiangxi are at the mild imbalance stage. Most western provinces such as Guizhou, Guangxi, Yunnan, Shaanxi, and Inner Mongolia are at the stage of mild imbalance stage. Xinjiang and Gansu are at mild imbalance stage. Besides, Qinghai and Ningxia are at a severe imbalance stage.

Guangdong in the eastern region still has the highest level of coordination in 2019, developing from the intermediate coordination to the good coordination stage. Compared with 2013, Shandong, Zhejiang, and Jiangsu reach to the next level, developing from the initial coordination stage to the intermediate coordination stage. After six years of development, Shanghai and Beijing have developed from bare coordination stage to the initial coordination stage. Anhui and Henan in the central region progress from on the verge of imbalance to bare coordination. Apart from that, Jiangxi and Hunan develop from mild imbalance to on the verge of imbalance. It is noteworthy that Liaoning, Jilin, and Heilongjiang in the Northeast region have no change in the coupling and coordination stage, which is more directly

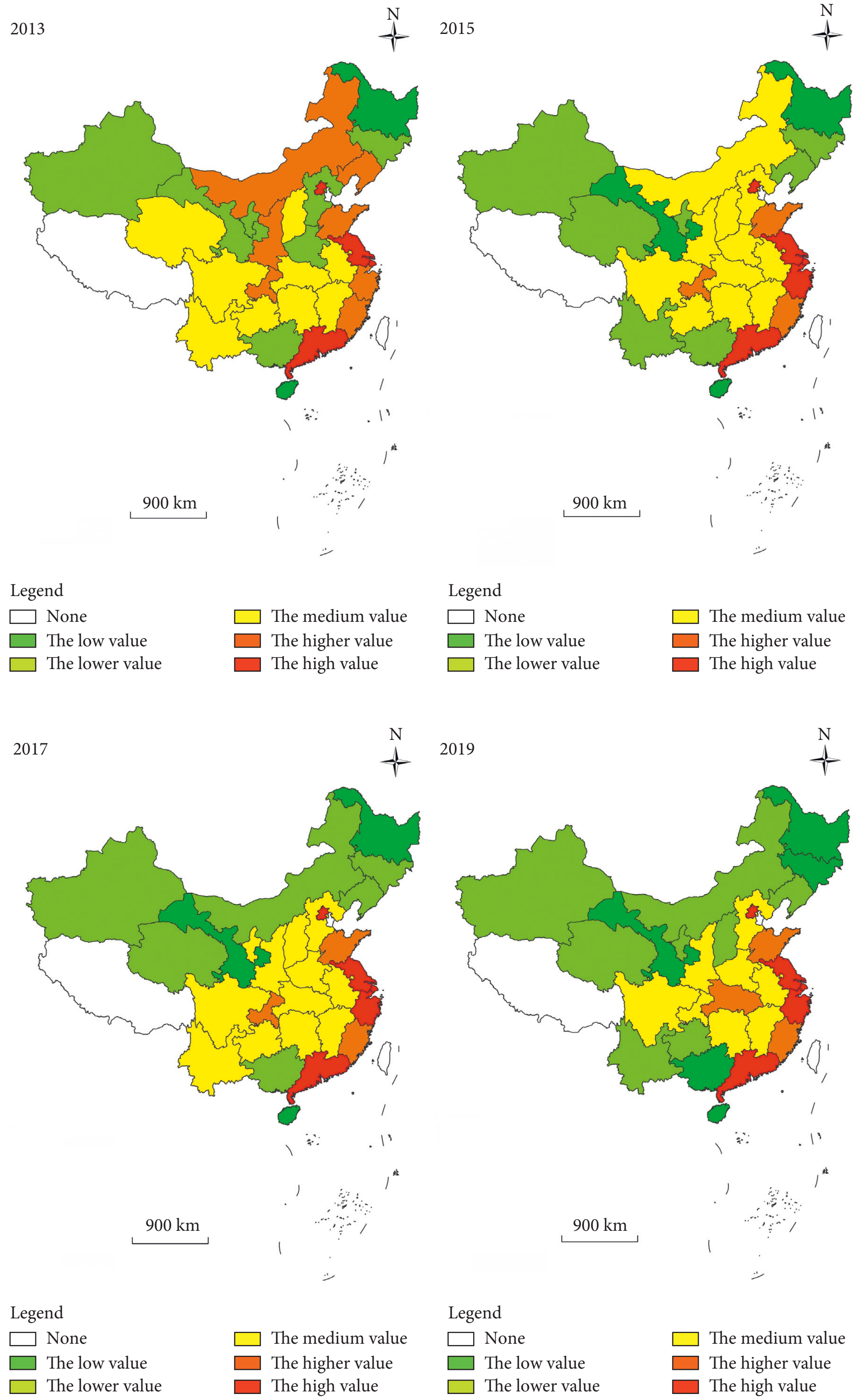

Figure 1: 2013–2019 provincial regional economy development level.

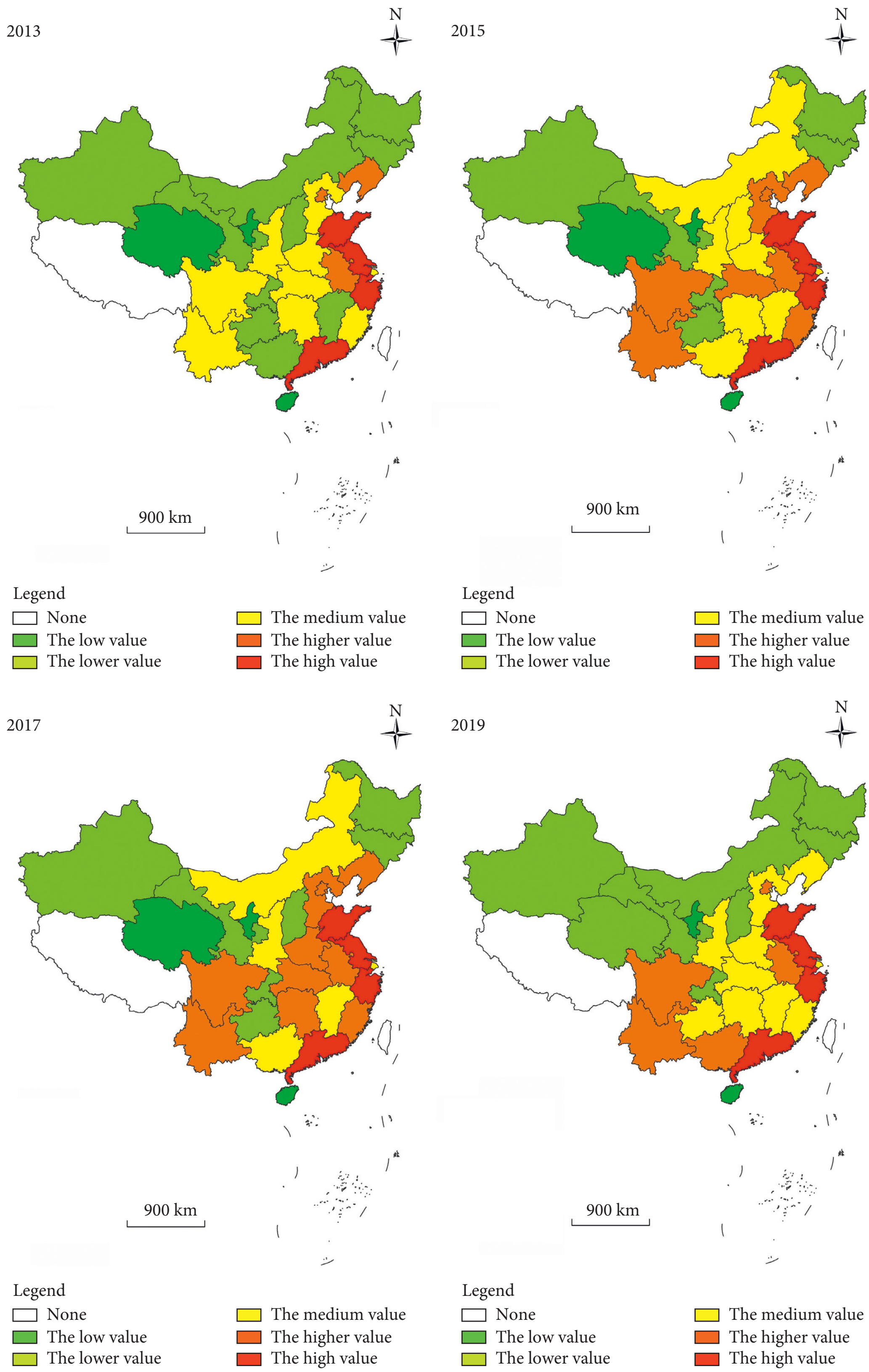

Figure 2: 2013–2019 provincial tourism industry development level.

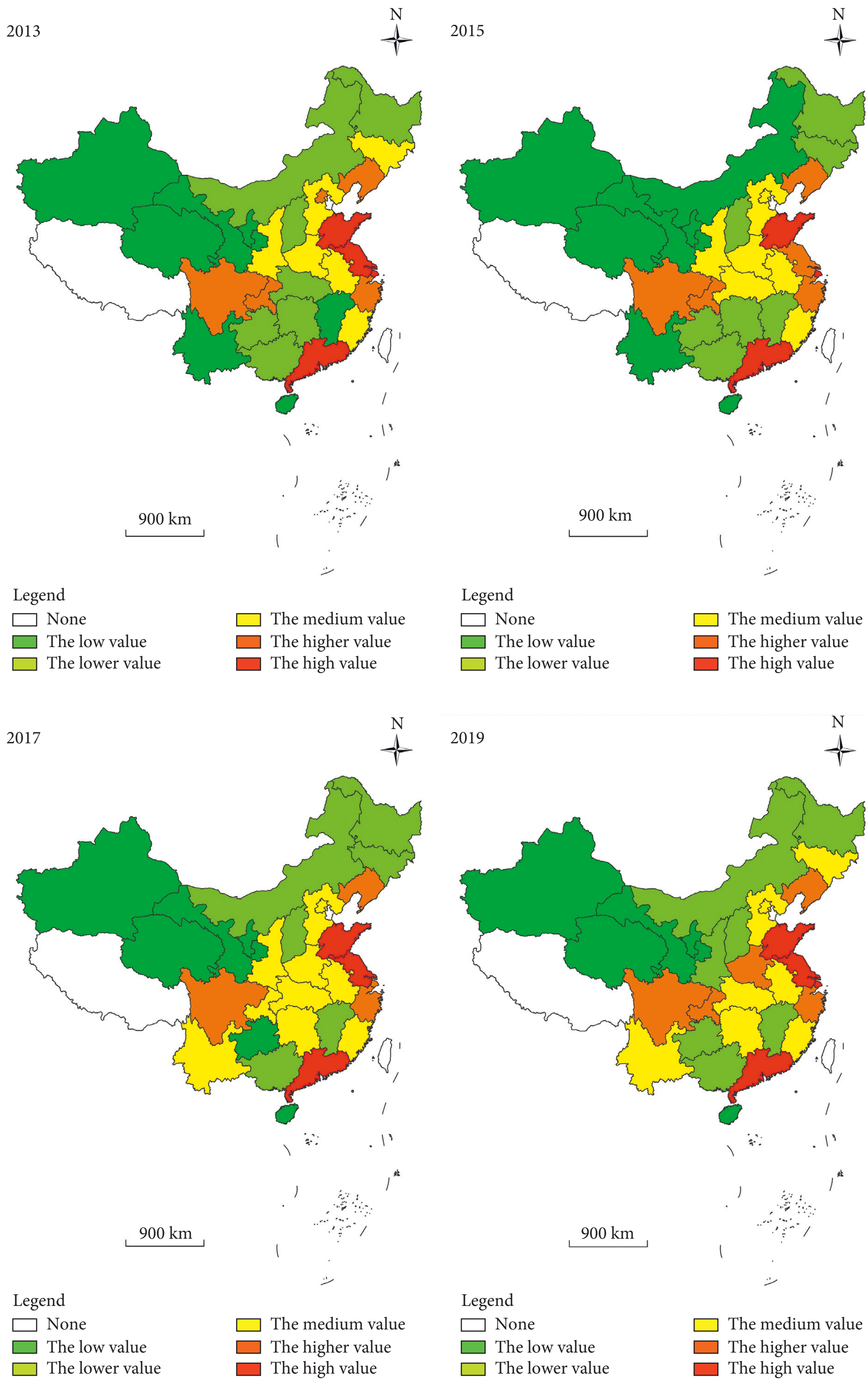

FIGURE 3: 2013–2019 provincial exhibition industry development level.

Table 2: The classification of coupling coordination degree of economy-tourism-exhibition.

Coupling and coordination	Interval	Province (2013)	Province (2015)	Province (2017)	Province (2019)
Wonderful coordination	0.9001–1				
Good coordination	0.8001–0.9000				Guangdong
Intermediate coordination	0.7001–0.8000	Guangdong	Guangdong, Shandong	Guangdong, Shandong Jiangsu	Shandong, Zhejiang, Jiangsu
Initial coordination	0.6001–0.7000	Shandong, Zhejiang, Jiangsu	Shanghai,, Zhejiang, Jiangsu	Shanghai, Zhejiang, Sichuan	Shanghai, Sichuan, Beijing
Bare coordination	0.5001–0.6000	Shanghai, Liaoning, Beijing, Sichuan	Sichuan, Liaoning, Beijing,	Liaoning, Beijing, Henan, Fujian, Anhui, Hunan	Chongqing, Liaoning, Henan, Fujian, Hebei, Anhui, Yunnan
On the verge of imbalance	0.4001–0.5000	Chongqing, Henan, Fujian, Hebei, Shaanxi, Anhui, Hubei	Chongqing, Henan Hubei, Fujian, Hebei, Shaanxi, Anhui, Guangxi	Chongqing, Hubei, Hebei, Shaanxi, Jilin, Jiangxi, Guangxi, Yunnan, Shanxi, Guangxi	Hubei, Shaanxi, Hunan, Guizhou, Jiangxi, Guangxi
Mild imbalance	0.3001–0.4000	Heilongjiang, Jilin, Hunan, Guizhou, Jiangxi, Guangxi, Yunnan, Shanxi, Inner Mongolia	Heilongjiang, Jilin, Hunan, Guizhou, Jiangxi, Yunnan, Shanxi, Inner Mongolia, Xinjiang	Heilongjiang, Guizhou, Inner Mongolia, Xinjiang, Gansu	Shanxi, Heilongjiang, Jilin, Inner Mongolia Xinjiang, Gansu
Moderate imbalance	0.2001–0.3000	Xinjiang, Hainan, Gansu	Hainan, Gansu,	Hainan, Qinghai	Hainan, Qinghai
Severe imbalance	0.1001–0.2000				Qinghai
Extreme imbalance	0.0000–0.1000	Qinghai, Ningxia	Qinghai, Ningxia	Qinghai, Ningxia	Ningxia

related to their dramatic decline in economic growth as well as slower development of tourism industry and exhibition industry. In the western region, Sichuan reaches to the next level, from the bare coordination to initial coordination. What's more, Guizhou, Shaanxi, and Guangxi develop from the mild imbalance to on the verge of imbalance. Yunnan develops more rapidly, from the mild imbalance to the bare coordination stage.

2.7. Gray Correlation. The basic idea of the gray correlation analysis method is to determine whether the sequence curves are closely related based on the similarity of their geometric shapes [22]. Generally speaking, the more similar the curves are, the greater the correlation between the corresponding sequences, and vice versa. With sample data from 29 provinces in China, respectively, this paper uses the time sequence data of coordination degree of the regional economy-tourism industry-exhibition industry from 2013 to 2019 as the reference series and conducts the gray correlation analysis to examine the degree of coupling and coordination between the regional economy-tourism industry-exhibition industry with indexes at each level. Apart from that, the primary indexes and secondary indexes are used as the influencing factors. The results of the gray correlation analysis of the coupling and coordination degree of the regional economy-tourism industry-exhibition industry with the primary and secondary indexes are displayed in Tables 3 and 4, respectively.

According to the results of the correlation measurement in Tables 3 and 4, the correlation between the coordination degree of regional economy-tourism industry-exhibition industry and 7 primary indexes and 15 secondary indexes is all above 0.6, indicating that all the indexes in the index system exert a greater impact on the coordination degree of regional economy-tourism industry-exhibition industry. The coupling and coordination degree of regional economy-tourism industry-exhibition industry is ranked in the order of correlation with seven primary indexes: economic structure, economic quality, the scale of tourism industry, economic sustainability, the efficiency of tourism industry, the scale of exhibition industry, and the efficiency of exhibition industry, in which the maximum value is 0.923 and the minimum value is 0.863.

The maximum correlation of the six secondary indexes of the economic system is 0.927, whereas the minimum correlation is 0.904. The correlation of the index of per capita disposable income is 0.923, the correlation of the index of per capita GDP is 0.922, the correlation of the index of the share of secondary industry is 0.918, and the correlation of the index of fiscal revenue is 0.910. In addition, the index with the smallest correlation among the five secondary indexes of the tourism system is the international tourist income with the value of correlation of 0.849, while the largest correlation is the number of starred hotels with the correlation of 0.929, the number of travel agencies with the correlation of 0.928, the number of A-grade scenic spots with the correlation of 0.922, and the domestic tourist income with the correlation of 0.895. The four secondary indexes of the exhibition industry system in the order of correlation from the highest to the lowest are as follows: the number of exhibitions, the area of professional exhibition venues, the area of exhibition venues, and the number of professional exhibition venues.

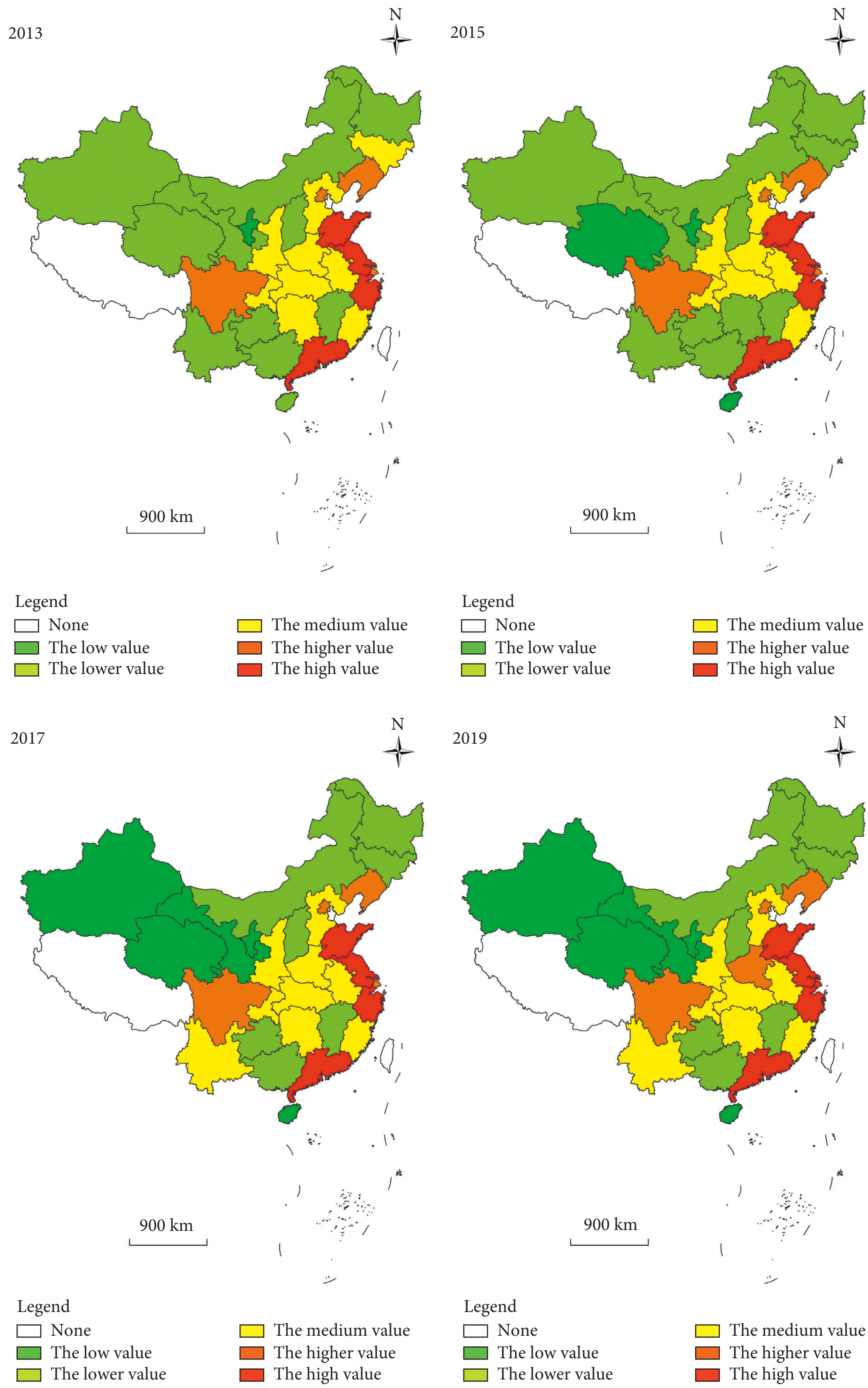

FIGURE 4: 2013–2019 provincial coupling and coordination level.

Table 3: Results of gray correlation analysis of measurement of primary indexes.

Subsystem	Primary indexes	Degree of association
Economic system	Economic quality	0.922
	Economic structure	0.923
	Economic sustainability	0.907
Tourism industry	Industry scale	0.920
	Industry efficiency	0.872
Exhibition industry	Industry scale	0.863
	Industry efficiency	0.863

Table 4: Results of gray correlation analysis of measurement of secondary indexes.

Subsystem	Primary indexes	Secondary indexes	Degree of association
Economic system	Economic quality	GDP per capita	0.922
		Per capita disposable income	0.923
	Economic structure	The proportion of secondary industry	0.918
		The proportion of tertiary industry	0.927
	Economic sustainability	Fiscal revenue	0.910
		GDP growth rate	0.904
Tourism industry	Industry scale	Number of travel agencies	0.928
		Number of A-grade scenic spots	0.902
		Number of starred hotels	0.929
	Industry efficiency	Domestic tourist income	0.895
		International tourist income	0.849
Exhibition industry	Industry scale	Number of exhibitions	0.864
		Exhibition area	0.862
	Industry efficiency	Number of professional venues	0.862
		Area of professional venues	0.863

3. Conclusion

This paper has examined the comprehensive development degree of the regional economy, tourism industry, and exhibition industry as well as the level of coupling and coordination of 29 provinces from 2013 to 2019 by constructing an evaluation index system for the coupling and coordination development of regional economy-tourism industry-exhibition industry.

(1) According to the results of the comprehensive development score, the regional economic development of each province, tourism industry, and exhibition industry shows a generally growing trend. Beyond that, the development level index presents a spatial distribution pattern of decreasing gradient from coast to inland in space.

(2) The integration of the economy-tourism industry and exhibition industry shows a continuous coordinated and benign development. On a national scale, the degree of integration and development of regional economy-tourism industry-exhibition industry in China has gradually developed and improved from bare coordination to good coordination. Apart from that, the degree of coupling and coordination of regional economy-tourism-exhibition industry varies greatly among provinces. Besides, the coupled and coordinated development of regional economy-tourism industry-exhibition industry in each province has obvious spatial characteristics, which generally shows the spatial characteristics of low in the central and western regions and high in the eastern region. Although some scholars have studied the coupling relationship between regional economy, tourism, and exhibition industry [1, 6, 7, 9, 10], they lack the research of the relationship between the three. In this study, the coupling coordination degree relationship between the three has been investigated.

(3) The gray correlation analysis has been made to explore the impact of the primary and secondary indexes in the coordination degree evaluation system on the coupling and coordination degree of regional economy-tourism industry-exhibition industry. As shown by the results, all the indexes could strongly influence the coupling and coordination degree of regional economy-tourism industry-exhibition industry. Compared with the exhibition industry system, the economic system and tourism system exert a stronger impact on the coupling and coordination degree of regional economy-tourism industry-exhibition industry.

This paper has two practical implications. First, the government makes a high degree of overall planning and strengthens the top-level design of “multicompliance.” In this regard, the government should make an overall plan and formulate a “multiregulatory integration” plan that integrates the national economy, tourism, exhibition industry, etc. Second, different regions should adjust measures according to local conditions. With a high degree of coupling and coordination, the eastern region continues to maintain the momentum of integration and development. In the central region, the coupling coordination degree is in the process of development. Thus, the central provinces should constantly improve the development level of coupling coordination. In addition, most of the western provinces have a low level of coupling and coordination. Hence, it is essential to speed up the improvement of the coupling and coordination level of these provinces.

Data Availability

The datasets used and/or analyzed during the current study are available from the author on reasonable request.

Conflicts of Interest

The author declares no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Research Article

Simulation of Tennis Spinning Ball Flight Path Based on Fuzzy Reasoning Algorithm

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Topspin is one of the most widely used hitting techniques in a tennis match and it is an effective tool to win over the opponent. Hence, flight path simulation of a spinning ball can be a tremendous analysis tool to help tennis players perfect their game. This article proposes a fuzzy logic model based on the principles of kinematics and mechanics. This study analyzes the physical characteristics of a spinning ball during the flight process, which are divided into two categories: the characteristics of the ball on impact (including the floating and rotating it causes) and the landing rebound characteristics. These two characteristics are considered as the constraints of the flight path simulation and the inputs of the fuzzy logic model. Fuzzy logic is used to fuzzify the impact and landing rebound information of the ball based on the knowledge base, solve the problem, and finally defuzzify the results into crisp outputs, that is, accurate flight trajectory. The simulation results show that the estimation error of the proposed model is lower than 3.7 cm/s and 0.9°, and the success rate of accurate topspin execution is 100%, indicating that the proposed model is effective to train tennis players.

1. Introduction

Tennis is known as the fifth most popular sport in the world [1, 2]. It is usually played between two single players (Singles) or two teams of two players (Doubles). Each player uses a racket to play tennis across the tennis court against their opponent who is on the other side of the net. The origin and development of tennis can be summed up in four words: it was bred in France, born in England, began to popularize and form a climax in the United States, and now it is popular all over the world.

The trajectory of a tennis ball's flight is extensively studied in the literature [3]. Topspin is a common technique resulting from a low to high swing path in the forehand groundstroke while keeping the racket surface vertical [4–6]. Accurate execution of this technique requires the tennis player to hone their technique and reduce their error. Developing a model to simulate the ball's trajectory in the case of a topspin hit would help coaches and players to better analyze their technique and improve their accuracy by training based on the analysis results [7]. Topspin is known for its high flying range, fast descent, small bounce angle, and large forward momentum [8–10]. The racket swings and rubs the whole ball from the lower back to the upper front and rotates it in the same direction. When the racket is hitting the ball, it will increase the amplitude of the upward-lifting and swinging, so that the ball will spin up sharply.

The rotation of a tennis ball in topspin has a very complex mechanical principle. Using the aerodynamic principle to analyze the topspin ball is a continuous action under different kinds of forces in the flight process [11–14]. Topspin creates translation and rotation kinetic energy [15, 16], making it difficult for the opponent to return to the ball. During the match, topspin not only bypasses the players at the net, but also gives the players in the baseline a false impression of going out of the boundaries. It is not easy to master topspin. Some players overemphasize the topspin of the ball which results in the lack of speed. Some players hit the ball with speed, but the topspin of the ball is not strong enough which may not be as accurate. Hence, it is very important to study the flight path simulation of topspin to improve the accuracy of players in executing this technique.

Although there are studies that investigate the ball trajectory simulation in some sports such as golf [17], table tennis [18–21], football [22–25], basketball [26], baseball [27], and handball [28], due to the difference between the physical characteristics of the ball that is used in these games, the simulation models are not applicable from one study to the other. There are multiple studies that strictly focus on investigating the physical behavior and characteristics of a tennis ball such as its impact with a tennis racket [29, 30] or a court surface [31], aerodynamics [32, 33], bounce physics [34], or simulating and predicting its impact behavior [35] and flight trajectory [36, 37] using mathematical models and computer algorithms. Among the most prominent studies on tennis ball simulation, Glynn et al. [35, 38] proposed to use forward dynamic computer simulation to simulate the physical characteristics of the impact between a racket and a tennis ball. And in another study, which is much closer in subject to this study, Kwon et al. [3] proposed to use correlational statistics to model and confirm the relationship between topspin angular velocity and racket kinematics. These studies account for parameters such as racket speed and impact angle. In a practical scenario, there are many more known and unknown parameters such as temperature or environmental pressure that impact the physical behavior of a ball and consequently its flight trajectory. However, such studies only rely on models which work with crisp values and do not account for these extra values. Methods such as fuzzy logic can account for these uncertainties to some extent.

Based on the concept of fuzzy reasoning and using the method of fuzzy logic to simulate human thinking and reasoning, the fuzzy information is comprehensively analyzed, and the fuzzy rules are deduced by using the fuzzy mathematical method [39–42]. A fuzzy reasoning algorithm is an advanced calculation framework based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. By using the reasoning mechanism, the high-precision output or conclusion can be obtained according to the known rules and facts. The fuzzy method has a good real-time performance and does not need to know the precise mathematical model of the controlled object [10, 43–45], which is suitable for the real-time requirements of tennis ball flight trajectory simulation with fast motion. Therefore, this article studies the flight path simulation of tennis topspin based on the fuzzy inference algorithm and discusses the flight motion law of tennis topspin starting from principles of mechanics. This study helps the players or practitioners to gain a more in-depth understanding of the trajectory of the topspin ball and continuously improve their skill in topspin the ball at a professional competitive level.

The contributions of this study can be summarized as follows:

(1) Proposing a mathematical model for tennis spinning and bouncing behavior

(2) Incorporating the fuzzy inference concept in the proposed mathematical model to account for uncertainties

The rest of this article is organized as follows: Section 2 reviews the most relevant studies in this field and discusses the research gap in the literature. Section 3 defines the target problem in this article. Section 4 reports the simulation and experimental setup and the obtained results. Section 5 discusses the practical implications and use cases of the proposed model. And finally, Section 6 concludes this article.

2. Literature Review

In this section, the researches that focus on tennis simulations and modeling, especially tennis ball physics modeling, are reviewed and the research gap that this study intends to fill is discussed.

2.1. Tennis Modeling. There have been many studies on the aerodynamics of tennis balls and how they behave in the environment in presence of forces such as gravity [46, 47]. Also, there have been some experimental studies that focus on gathering data on practical scenarios for different parameters and how a tennis ball reacts in a specific environment [7, 29]. Furthermore, there are more recent studies that have been conducted in the wake of technologies such as virtual reality and examine the accuracy and effectiveness of such environments in simulating sports such as tennis [37, 48]. However, researches that focus on a specific technique and try to use the obtained model both in computer simulations and practically are scarce. In this section, all the studies that focus on tennis ball movement modeling or simulation are reviewed.

Brody [34] modeled the bouncing action of a tennis ball from the court's surface. He made some simplified assumptions about the physical characteristics of the ball. He assumed that the ball is a hollow rigid object with no deformation and the court's surface is also hard and will not be deformed upon the ball's impact to the surface. Additionally, he used the simple law of friction to account for friction force on the court's surface and assumed that the horizontal and vertical motions of the ball are independent.

In another study, Jafri and Vance [31] modeled the impact of a tennis ball on a flat surface. They used a more complex two-mass model which accounts for the vertical translational motion with a spring and a damper in the vertical direction while using a torsional spring and a damper for the rotational motion of the masses.

Alam et al. [32] focused on the spinning motion of a tennis ball and modeled the effect of the ball's aerodynamics on the motion. As opposed to previous studies that considered the tennis ball to be a simple object, they accounted for the surface complexities of the ball in their model.

Glynn et al. [35] simulated the impact effects between a racket and a tennis ball using forward dynamic simulation. They proposed a detailed viscoelastic model for both the racket surface and the tennis ball. Their experiments indicate a less than 3% root mean squared error for the simulated rebound velocity in the range of 16 m/s to 27 m/s.

In one of the most prominent studies in this field, Kwon et al. [3] proposed to use racket impact angle, horizontal and vertical racket velocity before impact, racket trajectory, and hitting zone length as the effective parameters in modeling a topspin's angular velocity and the player's forehand accuracy. Their experiments and simulation results indicate that a racket impact angle of 70° to 85° is the most suitable angle for the proper execution of topspin technique. They also realized that increasing the racket's vertical velocity before impact is correlated with topspin angular velocity. However, the results show that parameters such as hitting zone length, racket trajectory, and racket horizontal velocity do not impact the angular velocity of the ball or the accuracy of the player. Hence, these parameters are not covered in this study.

Nadar et al. [27] proposed a model for tennis balls and baseballs based on computational fluid dynamics [49, 50]. They compared the two types of balls and defined certain characteristics such as surface roughness to differentiate between the two. They also propose to use free stream velocity and tangential direction of the ball movement to model the flight trajectory of the ball but fail to provide enough experimental results to thoroughly demonstrate the applicability of their proposed model in practical scenarios.

Studies such as [36, 51] mostly rely on image processing techniques to determine or predict the physical behavior of tennis balls or their flight trajectory. Ke et al. [36] proposed to use machine learning and neural networks to determine the impact coordinates of a tennis ball under certain conditions. Their proposed method requires a training dataset to train the model and video cameras to record each player's training sessions and analyze their training effectiveness and efficiency post-training.

2.2. Research Gap. As discussed in the previous subsection, there are a limited number of studies that strictly focus the topspin technique in tennis. However, multiple studies attempt to model different physical attributes and behavior in a tennis match, especially the physical interaction between the racket and the ball, and between the ball and the court surface.

Table 1 tabulates all the studies that have been discussed in the previous subsection. It is evident from this table that the topspin technique has the lowest number of researches dedicated to it. Also, all the other studies use deterministic models that do not account for data noise and unknown parameters that might impact the results and are not considered in the model. The proposed model in this article utilizes fuzzy inference while taking advantage of previously proposed models in the literature. Taking advantage of fuzzy inference reduces the negative impact of uncertainties in input data and can handle the impact of other unknown and ignored parameters, such as temperature, to some extent.

3. Problem Statement

This section defines the main problem. But before getting into the problem statement and discussing the proposed fuzzy inference model, basic physics principles of a tennis ball and its impact characteristics need to be discussed. Hence, the next subsection reports all the considered parameters and their notation. Then, the physics principles of the problem are discussed (Table2).

3.1. Notation List. 3.2. Kinematic Analysis of Tennis. Topspin has two stages in the flight process, namely the impact and the landing rebound of the ball [52]. Ideally, a tennis ball does not rotate in the air. However, most of the time it is affected by gravity, buoyancy, additional mass force, air resistance, and hitting height [53], which would lead to rotation during flight. The air resistance is opposite of the direction of tennis movement as shown in Figure 1. The impact of other parameters (gravity, buoyancy, additional mass force, and hitting height) is also depicted in this figure. When the speed of the ball changes very little, the additional mass force can be ignored.

3.2.1. Physical Characteristics of the Impact of a Tennis Ball. Let V be the speed of the ball. Then the air resistance, F, is calculated as:

$$F = \mu V. \tag{1}$$

If the tennis ball is impacted in the front, the loss function ΔT after the collision is related to the coefficient of recovery K [54], and the gravity on the tennis ball in flight m. If m^t is the mass of the arm, V_1 and V_2 represent the speed of the ball before and after the collision, respectively, then ΔT is defined as:

$$\begin{aligned}\Delta T &= \frac{m^t m}{2\left(m^t + m\right)} \\ &= \left(1 - K^2\right)\left(V_1 - V_2\right)^2.\end{aligned} \tag{2}$$

The change in tennis ball velocity V_2 after the collision can be expressed as:

$$V_2 = V_2 + (1 + K)\frac{m^t}{m^t + m}\left(V_1 - V_2\right). \tag{3}$$

If $J_z = (2/3)mR^2$ and w and R are the angular velocity of tennis and the resistance, respectively, then the kinetic energy of a tennis ball after a collision is expressed as:

$$T_2 = \frac{1}{2}mV_2^{t2} + \frac{1}{2}J_z w^2. \tag{4}$$

The trajectory of a spinning tennis ball is always subject to resistance R [55], which is the opposite of the direction of motion. Its range is usually in the high Reynolds range. If C_D is the resistance coefficient, then it is calculated as:

$$R = C_D \frac{1}{8}\pi d^2 \rho_0 V^2. \tag{5}$$

It has been shown that C_D can be expressed in three different formulas according to different Reynolds number ranges as:

Table 1: Survey on related works.

Reference	Research field	Method
[34]	Court impact physics	Simplified ball and surface model and simple law of friction
[31]	Court impact physics	Two-mass model, spring and damper in vertical direction, and torsional spring and damper for rotational motion
[32]	Spinning motion	Complex ball model
[35]	Racket impact physics	Viscoelastic model
[3]	Racket impact physics in topspin	Complex racket model
[27]	Spinning motion	Computational fluid dynamics
[36]	Racket impact physics and spinning motion	Machine learning image processing
This study	Racket impact physics, court impact physics, and spinning motion flight trajectory	Court surface and ball model, air and court friction model, and fuzzy inference

Table 2: The parameters, description, and related units of the problem.

Parameter	Description	Unit
V	Speed of the ball	Meter per second (m/s)
F	Air resistance	Newton (N)
K	Coefficient of recovery	-
m	Gravity on the ball	Meter per second squared (m/s^2)
m^t	Mass of the arm	Gram (g)
V_1	Speed of the ball before the collision	Meter per second (m/s)
V_2	Speed of the ball after the collision	Meter per second (m/s)
ΔT	Loss function after the collision	(m/s)^2
w	Angular velocity of the tennis ball	Radian per second (r/s)
T_2	Kinetic energy of the ball after collision	Joules (J)
C_D	Resistance coefficient	—
R_r	Reynolds number	—
F_c	Centripetal force	Newton (N)
v	Fluid velocity	Meter^3 per second (m^3/s)
p	Pressure	Dyne per square meter (D/m^3)
ρ	Air density	Gram per liter (g/l)
g	Gravity	Meter per second squared (m/s^2)
y	Potential	Joule per coulomb (J/c)
L	Lift	Newton (N)
C_L	Lift coefficient	—
λ	Threshold value of the fuzzy rule	—
d	Distance	Meter (m)
C_n'	Inference result	—
r^{COA}	Center of gravity of membership function	—

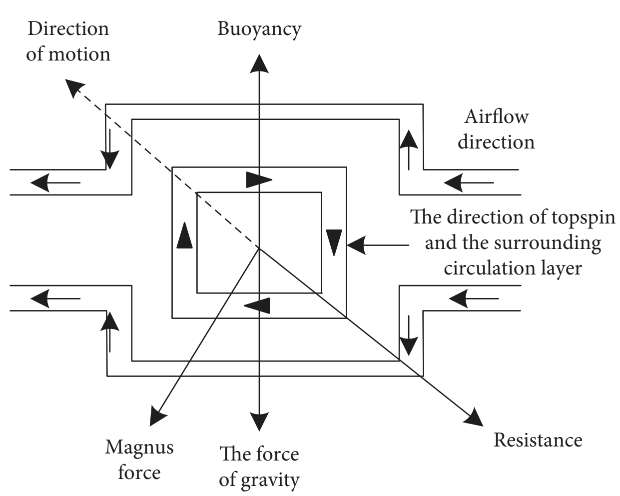

Figure 1: Aerodynamic analysis of the flight of a spinning tennis ball.

$$C_D = \frac{24}{R_r}\,(R_r < 1),$$
$$C_D = \frac{24}{R_r}\left(1 + \frac{R_t^{(2/3)}}{6}\right)(1 < R_r < 1000), \tag{6}$$
$$C_D \approx 0.44\left(1000 < R_r < 2 \times 10^5\right),$$

where R_r is the Reynolds number, and the resistance is proportional to the square of the velocity V.

After the tennis ball is hit, it encounters certain air resistance in the flight, which increases the pressure difference resistance. The vibration caused by the tennis ball being hit will produce simple harmonic vibration F_v to the air [56]. If H is the force amplitude, F_c is the centripetal force, and ϕ is the initial phase, then F_v is formulated as:

$$F_v = H \sin\left(F_c + \phi\right). \tag{7}$$

For a tennis ball in flight, the above parameters are all fixed values. Let v be the fluid velocity, p be the pressure, ρ be the air density, g be the acceleration of gravity, y be related to potential, and $c_1(4)$ be the constant, then the following equation would be obtained from the Bernoulli equation:

$$\begin{aligned}\frac{v^2}{2}+\frac{p}{\rho}&=gy\\&=c_1(4).\end{aligned} \tag{8}$$

The interaction between the circulation and the airflow changes the streamline distribution when a rotating sphere moves in the environment, forming a certain pressure difference [57]. According to Bernoulli's law, the lift $L = (1/8)C_1\pi d^2\rho V^2$ and the lift coefficient $C_L = (8L/(\pi d^2\rho V^2))$ are generated, where d is the diameter of the tennis sphere.

The difference between topspin and flat attack is that there is an upward and forward lifting action in topspin. Therefore, topspin causes the ball to have a movement of upward rotation around itself in the first stage of its flight. In topspin, the air pressure above the ball is large. Therefore, it will fall to the ground quickly when it drifts in the first stage after passing the net, which makes it hard to hit.

Compared to the flat shot, the rotation speed of the tennis ball is larger than the increase in V_1, so the rotation speed of the ball which is hit under the same conditions is larger than that of the flat shot in the second stage of flight. The pressure difference between the up and down airflow of the ball will further expand, resulting in its downward trend to increase simultaneously.

3.2.2. The Rebound Characteristics of Topspin. In the process of landing rebound after the ball is hit, its physical changes should be carried out from the horizontal and vertical force angles [58]. The force after the ball is hit includes different force changes in the horizontal and vertical directions. Hence, the speed of the ball is composed of horizontal and vertical components after being hit. In such an environment, the resultant force which changes the ball movement should be considered to analyze the final characteristics more rationally.

When a tennis ball moves forward in a horizontal throw, its velocity V is composed of horizontal velocity V_P and vertical velocity V_C. That is to say, the size of V after the rebound of the tennis ball is determined by the size of V_P and V_C, while the size of incident angle α_1 and reflection angle α_2 of the tennis ball is determined by the ratio of V_P and V_C at the moment of the landing of the ball. The above characteristic analysis is carried out in the simulation of the standing on state, excluding the external influence factors. This analysis result can explain the main relationship that causes the change in the speed of the ball being hit. The flatness of the side surface, the change of airflow, the gravity of the Earth, and the resistance of the controller will affect the impact and the rebound angle, but only to a lesser extent. The physical characteristics of the spinning ball when it is hit and the rebound characteristics of the landing of the spinning ball are regarded as the constraints of the simulation of the flight path of the ball.

3.3. Fuzzy Reasoning Algorithm

3.3.1. Principle of Fuzzy Reasoning. There are three basic reasoning modes in fuzzy reasoning [59], that is, fuzzy hypothetical reasoning, fuzzy refusal reasoning, and fuzzy syllogism reasoning. In this article, fuzzy hypothetical reasoning is used to simulate the tennis ball flight trajectory based on a fuzzy logic algorithm. Fuzzy hypothetical reasoning can be directly expressed as:

Rules: if x is A then y is B
Fact: x is A'
Conclusion: y is B'

In the fuzzy hypothetical reasoning of known facts, it is necessary to construct the corresponding fuzzy relation E [60] according to the fuzzy set in the fuzzy rules and then get the conclusion through a combination of known facts E.

If λ represents the threshold value of the fuzzy rule f, which is used to represent the application conditions of f, then the rule is defined as:

$$f\,x \text{ is } A \text{ then } y \text{ is } B(\lambda). \tag{9}$$

If the fact is known to be "x is A'," A' and A can be fuzzy matched, the conclusion "y is B'" can be obtained from the fuzzy hypothetical reasoning. If E represents the fuzzy relation between A and B, the fuzzy set B' can be obtained from the following composite operation:

$$B' = A' \circ E. \tag{10}$$

There are many ways to construct the fuzzy relation between two fuzzy sets. Here, the minimax rule of a conditional proposition is adopted, and its construction form is defined as:

$$\begin{aligned}A&=\int_U \mu_A\frac{(u)}{u},\\B&=\int_U \mu_B\frac{(v)}{v}.\end{aligned} \tag{11}$$

Then the fuzzy relationship between A and B can be defined as:

$$\begin{aligned}E(A,B)&=(A\times B)\cup(\overline{A}\times V)\\&=\int_{U\times V}\frac{(\mu_A(u)\,\mu_B(v))\vee(1-\mu_A(u))}{(u,v)}.\end{aligned} \tag{12}$$

3.3.2. Establishing the Fuzzy Reasoning Algorithm. According to the kinematic characteristics of a spinning tennis ball, the flight path is determined by two factors, namely the impact of the racket and the landing rebound of the ball. As shown in Figure 2, the two inputs of the fuzzy reasoning algorithm are the impact of the tennis ball and the landing rebound of the tennis ball [61].

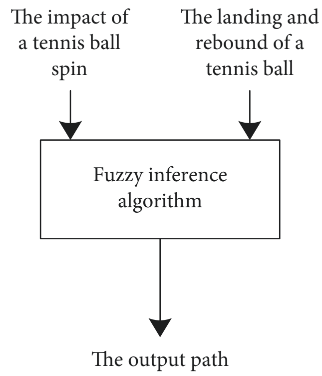

Figure 2: Fuzzy inference algorithm.

(1). Fuzzy sets and membership functions. The linguistic variable of the impact speed of the tennis ball is represented by d, the domain is $X = [0, 600]$, the fuzzy subset of its response is $A_i\,(i = 1, 2, 3, 4, 5)$, and the corresponding linguistic value is {"minimum," "small," "medium," "large," and "maximum"}, using trapezoid membership function [62], as shown in Figure 3.

For the landing rebound of the tennis ball, the proportion of the linear distance between two endpoints in the flight path and their projected distance in the x direction is determined [63]. The linguistic variable of the signal is t, the domain is $Y = [0, 1]$, the corresponding fuzzy set is $B_i\,(i = 1, 2, 3, 4, 5)$, and the corresponding linguistic value is {"minimum," "small," "medium," "large," and "maximum"}. The trapezoidal membership function is adopted as shown in Figure 4.

For the output, the linguistic variable is g, which represents the scenario in which the line deviating from the starting point is close to the x-axis [64], the domain is $Z = [-180, 180]$, the corresponding fuzzy subset is $C_i\,(i = 1, 2, 3, 4, 5)$, the corresponding linguistic weight is {"minimum," "small," "medium," "large," and "maximum"}. The trapezoid membership function is adopted as shown in Figure 5.

(2) Fuzzy inference rules. According to the starting point in the flight path and the requirements of the fast and stable motion, a series of fuzzy inference rules are developed as shown in Table 3.

In this article, Mamdani fuzzy inference [65, 66], namely the min-max inference method, is used for fuzzy logic and defuzzification. Considering that the distance is d, the proportion is t, that is, each fuzzy rule is represented as A_i and $B_i \Rightarrow C_k$, and $\wedge$ is min, that is, the minimum value, the inference result C_n' can be obtained as:

$$u' c_n(r) = u_{A_i}(d_0) \wedge u_{B_i}(h_0) \wedge u_{C_k}(r). \tag{13}$$

Hence, C' is the result of comprehensive reasoning on C_n'. Let $\vee$ be Max, that is, the maximum value, then:

$$u_{c'}(r) = u_{c_1'}(r) \vee u_{c_2'}(r) \vee \cdots \vee u_{c_i'}(r). \tag{14}$$

The rotation direction and angle of the moving object corresponding to the fuzzy set C' are obtained as:

$$r^{\mathrm{COA}} = \frac{\int_z r u c'(r) \mathrm{d}r}{\int_z u c'(r) \mathrm{d}r}. \tag{15}$$

The value of r^{COA} is the center of gravity of the membership function of the fuzzy set C'. The crisp defuzzied output results are the final obtained flight path of the tennis ball.

4. Results

The practice of tennis spinning shows that for high-level players, the hitting speed is the primary factor affecting their playing quality. For the same player, the hitting height is relatively fixed, but the hitting position and the swinging speed can be changed. Therefore, during the simulation, the tennis spinning track with different hitting speeds and fixed height is simulated. Experiments are performed on the flight path of tennis spinning ball with different hitting angles under the conditions of fixed hitting height and hitting speed. To simulate the flight path of a tennis ball, the proper coordinate system is established, and the effective fall point range is calculated to find the average speed error and the average method error.

4.1. Simulation Results at Different Impact Speeds. This experiment is used to determine the flight path parameters of a spinning ball, including the height from the racket to the ground, the impact speed, the angle between the initial speed and each axis, and the rotation speed. The simulation is divided into two parts: the first part studies the impact speed of tennis on the flight path under the same hitting height and hitting angle; the second part studies the impact of hitting angle on the flight path under the same hitting height and hitting speed. Table 4 shows the simulation parameters at different impact speeds.

Assuming that the impact coordinates are (1, 0, 2.8), Figure 6(a) is to simulate the relationship between the impact speed of the tennis ball and the x-coordinate of the landing point by using the method in this article. The effective range of x is (−4.115,0). Figure 6(b) shows the relationship between the impact speed of the ball and the y-coordinate of the landing point. The effective range of y is (11.885,18.285).

It can be seen from Figure 6 that in the case of considering air resistance and Magnus force, there is an error between the falling point of a spinning ball and the ideal falling point, and the faster the ball speed is, the greater the error is. It can be seen from Figure 6(a) that under the same impact height and angle, the larger the initial speed of the spinning ball is, the farther the x-axis falling point is from the centerline. Considering that the air resistance is not considered compared with Magnus's force, the falling point of the tennis ball on the x-axis is far from the centerline. It can be seen from Figure 6(b) that under the same impact height and angle, the larger the impact speed of tennis is, the farther the y-axis falling point becomes. Considering that the air resistance is not considered compared with Magnus's force, the falling point of the tennis ball on the y-axis is closer. The

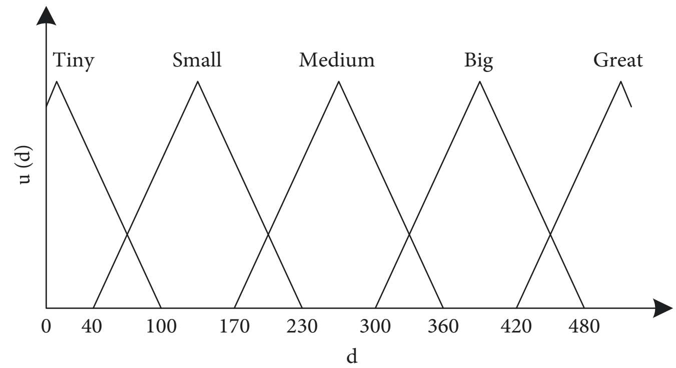

Figure 3: Membership function of the fuzzy subset A_i.

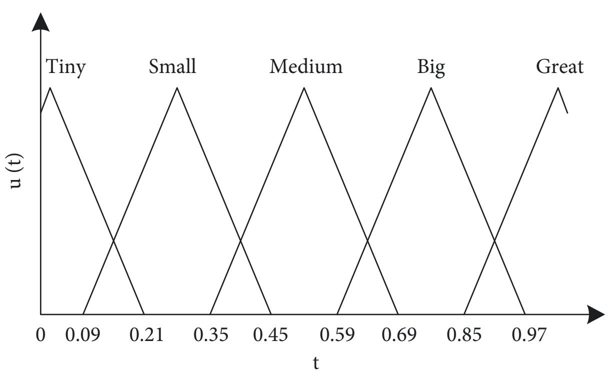

Figure 4: Membership function of the fuzzy subset B_i.

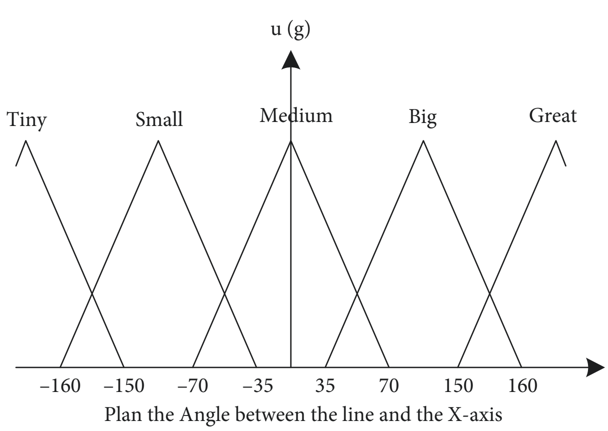

Figure 5: Membership function of the fuzzy subset C_i.

Table 3: Fuzzy inference rules.

Speed	Speed				
	Tiny	Small	Medium	Big	Great
Tiny	Tiny	Tiny	Tiny	Small	Medium
Small	Tiny	Small	Small	Medium	Big
Medium	Tiny	Small	Medium	Big	Great
Big	Small	Medium	Big	Big	Great
Great	Medium	Big	Great	Great	Great

Table 4: Simulation parameters at different impact speeds.

Project	Parameter value
Gravitational acceleration	9.7 m/s^2
Quality of tennis	0.056 kg
Air density	1.104 kg/m^3
Tennis ball diameter	0.0643 m
The height at which a tennis ball spins off the racket	2.7 m
The angle between the velocity of impact and the x-axis	97.77°
The angle between the velocity of impact and the y-axis	8.77°
The angle between the velocity of impact and the direction of the z-axis	99°
Angular velocity of rotation	49 rad/s
Lift coefficient	0.4
Resistance index	0.3

simulation verifies the influence of air resistance and Magnus force on the flight trajectory of the tennis ball.

4.2. Simulation Results under Different Impact Angles. Table 5 shows the simulation parameters of the impact angle's influence on the flight path of a spinning ball under the same impact height and speed. The angle here mainly refers to the angle between the racket surface and the z-axis.

Suppose that the impact point coordinates of the tennis ball are (1, 0, 2.8), Figure 7 (a) depicts the relationship between the impact angle and the x-coordinate of the impact point. The effective range of x is (−4.115,0). Figure 7 (b) shows the relationship between the impact angle of the tennis ball and the falling point. The effective range of y is (11.885,18.285).

In Figure 7, the impact angle of the x-axis is the angle between the tennis ball speed direction and the negative z-axis direction. It can be seen from Figure 7 that the faster the speed of the ball is, the larger the error between the ideal landing point and the actual landing point is when considering air resistance and Magnus force. It can be seen from Figure 7 (a) that under the same impact height and speed, the larger the impact angle of the tennis ball is, the closer the impact angle is to the horizontal direction and the farther the x-axis drop point would be. Considering the air resistance and Magnus force, the x-axis drop point of the tennis ball is

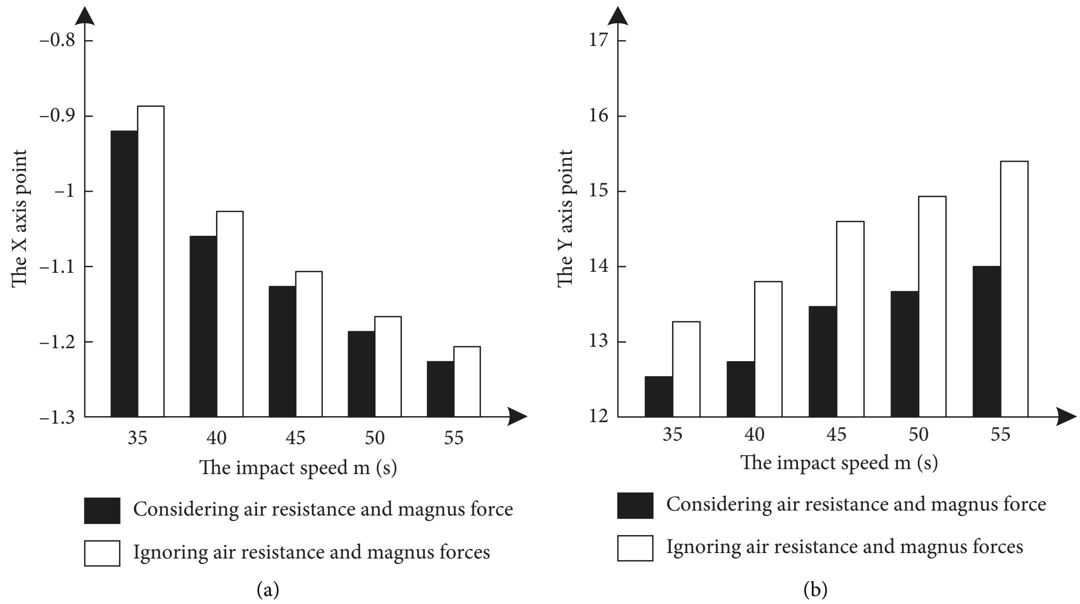

Figure 6: Relationship between the impact velocity of a tennis ball and the coordinates of its landing point: (a) x-coordinate and (b) y-coordinate.

Table 5: Simulation parameters without impact angle.

Project	Parameter value
Gravitational acceleration	$9.7\,m/s^2$
Quality of tennis	0.056 kg
Air density	$1.104\,kg/m^3$
Tennis ball diameter	0.0643 m
The height at which a tennis ball spins off the racket	2.7 m
The angle between the velocity of impact and the x-axis	97.77°
The speed with which a tennis ball spins	44 m/s
Angular velocity of rotation	49 rad/s
Lift coefficient	0.4
Resistance index	0.3

far away from the centerline than ignoring the air resistance and Magnus force. It can be seen from Figure 7(b) that under the same impact height and angle, the larger the impact angle of the tennis ball, the closer the impact angle is to the horizontal direction and the farther the y-axis drop point would be. Considering the air resistance and Magnus force, the distance of the tennis ball is closer when the y-axis drop point is less than when the air resistance and Magnus force are ignored. This simulation shows that in the tennis ball impact process, it is necessary to choose the right impact angle; otherwise, it would be easy to make mistakes in a topspin move.

4.3. Comparison of Simulation Results of Different Methods. To verify the simulation performance of this method, the experiment compares the speed error, the direction error, and the success rate of the spinning action executed by tennis players after training based on the current method and two flight path simulation methods based on multi-process state equation and data mining, respectively. The results are reported in Tables 6–8 . From Tables 6–8, it can be seen that the speed error, direction error, and spinning success rate of the players in the training process are significantly better than those of the two compared methods after using the method that is proposed in this article. The average speed error and the average method error are lower than 3.7 cm/s and 0.9°, respectively, and the spinning success rate of 10 players is 100%. When the multi-process state is used, the average speed error and the average method error of the athletes trained by the equation simulation method are lower than 6.4 cm/s and 1.7%, respectively, and the success rate of spinning is between 91.67% and 97.56%. Also, the average speed error and the average method error of the athletes trained by the data mining simulation method are lower than 6.1 cm/s and 2.8%, respectively, and the success rate of spinning is between 89.19% and 97.50%. The experimental results fully demonstrate that the proposed method positively impacts the tennis players' spinning training.

4.4. Discussion. This article proposes a simulation model for the flight trajectory of a topspin spinning ball based on the fuzzy logic algorithm. According to the kinematic characteristics of tennis spinning ball flight, it is found that the tennis spinning ball flight path is determined by two factors: the impact height, angle, and speed of the ball; and the landing rebound of the tennis spinning ball. By using the fuzzy inference algorithm, the information of these two factors is fuzzified by the fuzzy rules that are established previously and the defuzzification process is carried out to obtain crisp results. These results present an accurate output path obtained by the simulations. The results show that the

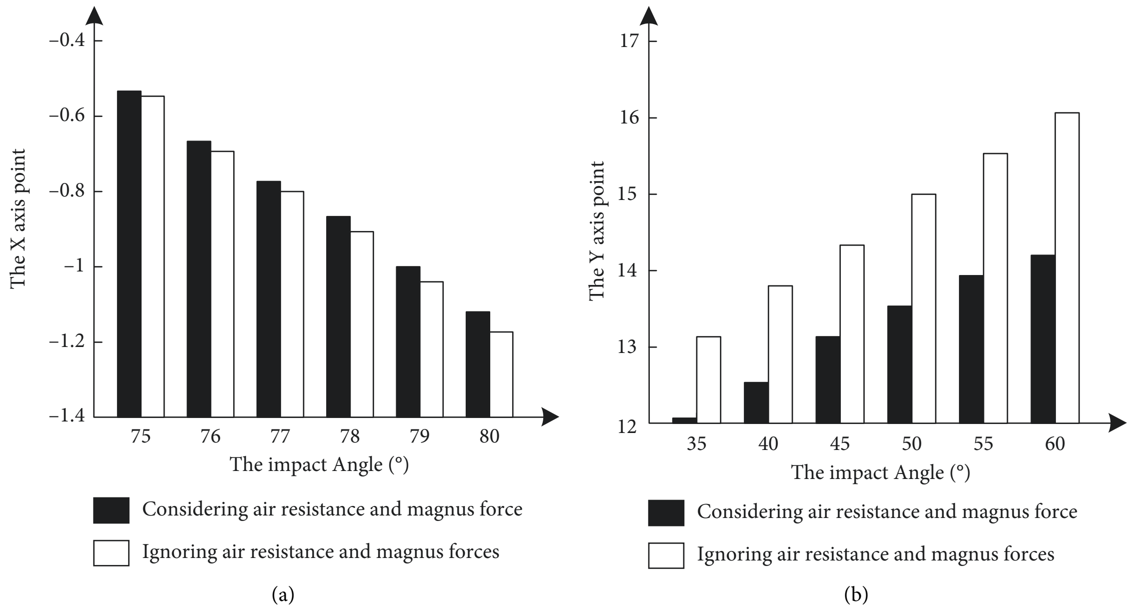

Figure 7: Relationship between the impact angle and the coordinates of its landing point: (a) x-coordinate and (b) y-coordinate.

Table 6: Training results of athletes after using this method.

Player number	Spin ball practice times (times)	Average error of flat velocity (cm/s)	Average directional error (°)	Spin success rate (%)
1	42	3.31	0.72	100
2	38	3.42	0.88	100
3	37	3.49	0.85	100
4	40	3.53	0.69	100
5	38	3.30	0.78	100
6	39	3.66	0.58	100
7	36	3.41	0.62	100
8	32	3.58	0.53	100
9	40	3.35	0.39	100
10	32	3.31	0.87	100

Table 7: Training results of athletes after using the method of multi-party process equation of state.

Player number	Spin ball practice times (times)	Average error of flat velocity (cm/s)	Average directional error (°)	Spin success rate (%)
1	40	5.82	0.93	95.00
2	41	5.44	1.68	97.56
3	38	6.22	1.44	94.74
4	42	5.76	1.39	95.24
5	36	5.29	1.41	91.67
6	35	5.81	0.99	97.14
7	38	6.06	1.06	94.74
8	36	6.33	1.35	97.22
9	35	5.74	1.60	94.29
10	40	5.90	1.28	95.00

x-axis deviation is not significant, and the y-axis change is more obvious. When the impact height and impact angle are the same, the faster the impact speed is, the larger the deviation of the ball's falling point is. Also, when the impact height and speed are the same, as the impact angle increases, the more obvious the ball's falling point deviation would be, especially at 79° to 81°. Comparing the results of the three different simulation methods shows that the average speed error, the average direction error, and the success rate of the tennis players accurately executing a topspin move are significantly better than those of the two other methods. The main reason for this method to achieve such good results is

Table 8: Training results of athletes after using data mining method.

Player number	Spin ball practice times (times)	Average error of flat velocity (cm/s)	Average directional error (°)	Spin success rate (%)
1	38	5.12	2.83	92.11
2	40	6.09	2.65	95.00
3	40	5.95	2.52	97.50
4	36	5.32	2.74	91.67
5	37	5.61	2.09	94.59
6	41	5.40	2.28	92.68
7	37	5.13	2.69	89.19
8	38	4.99	2.06	94.74
9	34	5.46	2.76	94.12
10	36	5.77	2.13	91.67

that this method adopts a fuzzy reasoning algorithm. As a branch of approximate reasoning, the fuzzy reasoning algorithm is the theoretical basis of fuzzy control and also a very important intelligent algorithm. The fuzzy reasoning algorithm has a strong ability in dealing with complex process control with uncertainty (e.g., input sensor or environment noise) and nonlinearity which is difficult to be modeled by traditional mathematical tools such as differential equation and is highly effective and complements other technologies and models perfectly.

To improve the scientific training level of the tennis topspin technique, the following three suggestions are presented:

(1) Tennis players should pay attention to the dynamic basic theory of ball flight to master the changing characteristics of topspin flight trajectory and improve their execution quality.

(2) Tennis players have a great difference in ball speed when hitting the ball. Hence, they should pay attention to the training of impact speed and adjust the impact angle properly when performing topspin to improve their success rate.

(3) In the relatively fixed period, when the players spin the ball, the ball speed of the players will not change much. Hence the players should pay attention to the adjustment of the impact angle, which should not fluctuate largely. They should gradually change the hitting angle in the training to find a more suitable angle.

5. Managerial Insights and Practical Implications

Simulating a tennis match with all the physical contributing parameters can be an invaluable tool in the hands of professional tennis players and their coaches. However, such a simulated environment requires very complex algorithms and powerful computer systems to process the computational load of such an environment. Hence, many separate studies and researches are required to be able to cover all the aspects of simulating such an environment. One of the aspects of simulating a tennis training environment is simulating different physical attributes of the related objects in the game. As discussed in Section 2, many studies focus on modeling the physics of rackets, balls, and court surfaces to determine the flight trajectory or impact coordinates of a tennis ball. However, instead of trying to model the whole behavior of the tennis ball in different situations and scenarios, this study only focuses on a single technique (topspin) and simulates the behavior of the ball of the court surface only with regards to this technique. Such an approach is much more fine-grained compared to other studies and as demonstrated in the previous section, outperforms them from an accuracy and efficiency perspective. This indicates that further studies in this field need to be focusing on individual techniques to achieve a certain level of accuracy. After covering a significant number of necessary tennis techniques, it would be possible to put all the obtained models together to develop an effective and accurate tennis training environment. This would help sport managers, coaches, and players tremendously and pushes the professionalism of the sport to levels that were believed to be impossible before the advent of such training tools.

6. Conclusions

The flight path of the tennis ball is an arc that causes the ball to drop sharply after passing the net. The player can hit a short diagonal ball and force the opponent to run out of the court to get the initiative. A topspin is also a good technique to disrupt the opponent's quick access to the balls that rebound from the surface of the court near the net. The lower topspin ball falls at the foot of the other side of the net, making it difficult to fight back. It is not hard to see that the spinning ball can attack and defend, has great power and high safety coefficient, and is a powerful weapon to defeat the enemy. This article proposes a simulation model for a spinning ball flight path based on the fuzzy logic algorithm in conjunction with the basic kinematic characteristics and mechanical principles of spinning balls. The proposed model uses fuzzy inference to simulate the high-precision spinning ball flight trajectory. The experiment results show that

(i) The average speed error is lower than 3.7 cm/s

(ii) The average method error is lower than 0.9°

(iii) The execution success rate of 10 players is 100%

The last observation is the direct result of improvement in the level of scientific training. In our future studies, we need to improve the fuzzy rule base and consider more relevant parameters such as temperature and more complex court surface properties to decrease the average speed error and average method error of the athletes. Also, different techniques such as serving are also a viable field for similar studies to develop a fully functioning tennis simulation environment step by step with accurate physical modeling.

Data Availability

There are no available data for this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

A Fuzzy Multi-Objective Mathematical Model for Supplier Evaluation in a Reliable Supply Chain considering Different Risk Levels

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One of the advantages of sustainable competition for manufacturing systems is to make supply chain activities more efficient and effective. One of the major parts of these activities that can save a lot of costs is careful outsourcing. In this study, an approach based on decision-making policies in order to select suppliers and allocate order volume to them is introduced. The main contribution of this research is a comprehensive approach for optimizing both supplier evaluation and order allocation. In this regard, first, based on the evaluation, 39 key indicators were identified to evaluate the suppliers, and based on the content analysis, 25 key indicators were screened based on the Lavache method. Next, based on the fuzzy Delphi method, 11 indicators were selected from among the 25 key effective indicators. Finally, the Best-Worst Method (BWM) and a robust multi-objective formulation are proposed to find the weight of the effective criteria and the optimal order allocation to suppliers, respectively. Moreover, it is proved that the company under study faces a variety of suppliers and there is a need to analyze key indicators such as exchange rate changes and ease of communication. Based on the BWM results, it was shown that the exchange rate change trend with a weight of 0.24 is in the first place, and the quality system support index with a weight of 0.12 is in the second place. Moreover, based on the results of the proposed robust multi-objective mathematical model, it was revealed that in order to maintain the resilience of suppliers, the total demand should be distributed among all suppliers and the second supplier with a volume of 3600 units of raw materials has the largest share in delivering the required demand.

1. Introduction

Nowadays, supply chains play a key role in the global economy. The competition between companies has given way to competition between supply chains. In other words, a network of companies is responsible for converting raw materials into final products and delivering them to the customer. This network of entities is responsible for various supply, production, storage, and distribution processes known as a supply chain. Regulators widely recognize the requirements for sustainable development. Organizations and consumers can act according to the definition of sustainable development to meet the current needs of society without compromising the ability of future generations to meet their needs. Therefore, a global perspective is needed to improve economic growth in sustainable development by emphasizing the relationship between the environment and social components [1].

One of the advantages of sustainable competition for manufacturing systems is more efficient and effective supply chain operations. One of the significant parts of these activities that can save many costs is the careful outsourcing of the organization's supplies [2]. Outsourcing the management of logistics activities, in addition to being an important resource for creating competitive advantages, can also provide customer satisfaction and meet their needs. Moreover, logistics network design integration is also of great importance for this reason [3]. Supply chain outsourcing has evolved as a new area of management research to help companies recognize potential resources and overcome operational and strategic challenges.

In recent years, evaluating the supply chain performance has attracted attention in the field of production and operations management [4, 5]. On the other hand, outsourcing evaluation and supplier selection policies are a challenge in which all areas of success and failure of organizations depend on the success or failure of outsourcing [6]. In such cases, decision-makers must use an optimal approach to allocate their available resources to achieve the best results.

Failure risk is one of the most likely situations in evaluating suppliers based on companies' incorrect supply policies [7]. Therefore, supply chain management is one of the components of competitive strategies for organizational productivity and profitability. Managers in many industries, especially manufacturing sectors, try to manage the supply chain better and evaluate their performance continuously [6].

In the supply chain, evaluating the performance of suppliers is one of the major challenges. One of the most important tools is a distinctive framework for evaluating suppliers by considering effective indicators using decision-making techniques. Therefore, outsourcing the management of the entire supply chain is a very difficult and challenging task. An organization will be economically efficient if it is technically and professionally efficient. Supply chain management coordinates all of these activities such that customers can obtain quality products and reliable services at a minimal cost.

In this study, a mathematical model is provided for evaluating the suppliers of a multi-level supply chain as well as assigning orders to qualified suppliers. In this regard, first, the effective indicators in evaluating the suppliers are extracted using the fuzzy Delphi analysis. Next, the best and worst indicators to evaluate supply chain outsourcing components are implemented using the BWM. It should be noted that the best and most qualified suppliers which are selected from the BWM are put as the set of available suppliers for assigning orders. Finally, a multi-objective model is proposed to find the optimal order allocation in the supply chain.

The main contribution of this research is based on presenting an integrated model of supplier evaluation and order volume allocation in the space of demand and supply uncertainty, as well as identification and selection of supply chain indicators based on literature review and the fuzzy Delphi analysis. According to the review of research literature, in most research items, the exploratory factor analysis method and classification of factors have been done by the PCA method, and the innovation considered in this section is the use of the fuzzy Delphi analysis, which according to the evaluation of incompatibility of opinions is highly accurate. In addition, to the best of the authors' knowledge, no research has been done in the field of order allocation in the supply chain, taking into account the demand uncertainty and implementing robust counterpart formulation for dealing with demand uncertainty.

2. Related Works

Supplier selection is an important issue for most supply chains. This issue was assessed first by Hulme [8] in 1963. In recent years, the importance of supplies in supply chain management has cleared for most real cases [9]. In order to facilitate the process of developing a supply chain, it is necessary to deal with the uncertainty in the raw material supply [7]. Therefore, it can be claimed that the right choice of suppliers can help the supply chain's success and, in the long, have a significant impact on the reliability of the final products [8].

Choosing the right supplier requires the consideration of several criteria. Decision-making is an issue that human beings have faced since its creation. Eventually, with the advancement of science and technology, human needs have changed dramatically. As it turns out, each person is faced with a variety of issues during the day and night that they must make the best decision. The science of decision-making has grown in various disciplines, including management, engineering, and operations research with scientific management. As society becomes more complex, goals become more numerous and conventional [5]. It is always necessary for organizations to strike a balance between their many conflicting goals, such as economic growth and efficiency. Industrial or commercial companies have also realized that they need to set several goals to make better decisions.

From the set of operations research techniques, decision-making techniques with multiple criteria are responsible for solving such problems in decision-making. In models such as linear programming, integer programming, nonlinear programming, and major classical operations research models, only one criterion such as profit, cost, efficiency, time, etc., is considered, while in multi-criteria decision-making models, several criteria are used simultaneously [6, 10].

The importance of supply chain management lies in the definition of the supply chain. Pourghader chobar et al. [7] define a supply chain as follows: Supply chain is a set of organizations that are divided into upstream and downstream organizations and seek to create value for the end customer through a product or service and through various activities and processes. The supply chain includes all activities related to the flow of products and the conversion of materials, from the stage of preparation of the raw material to the stage of delivery of the final product to the consumer. More broadly, a supply chain consists of at least two or three organizations legally separate and interconnected by material, information, and financial flows (Figure 1). These organizations can be organizations that produce end products and components and even include logistics service providers and the end customer themselves. Reference [11].

The purpose of supply chain management is to improve the efficiency of the supply chain process such that the right product reaches the customer in a timely manner and at the lowest cost. The belief that supply chain management can lead to better customer response and ultimately greater profitability has led many managers to consider supply chain

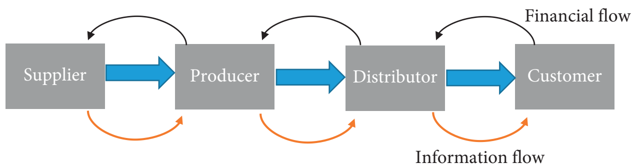

Figure 1: The flows in a supply chain.

management. Saeedi Mehrabad et al. [12] have identified the drivers of organizations toward supply chain management as follows: the need for improvement activities, increasing the level of outsourcing, supply chain complexity, the importance of global trade, increasing globalization, competitive pressures, increasing shipping costs, and the need for inventory management. Many authors have worked on green supply chain management as one of the most popular emerging environmental management methods. The emergence of this type of literature dates back to 1990 when companies became aware of the environment and supply chain management with the advent of environmental management [13].

Prior to 2000, there were few papers on logistics management, green supply chain management, and the environment, but later much research was done on environmental issues and threats to human life. Due to global warming and oil price fluctuations, more emphasis was placed on environmental protection, which led to much research into the development of green supply chain management concepts and theories. Today, many research efforts focus on examining the relationship between green/environmental factors and organizational/environmental performance. Green supply chain management advocates productivity and synergy between partners and facilitates environmental performance. Waste minimization and cost saving have attracted increasing interest from researchers and operations and supply chain management. Green supply chain management has emerged as an important new model for companies to achieve profit goals and market share by reducing their environmental impacts and risks along with increasing their ecological efficiency [6–9].

Mirhedayatian et al. [13] proposed the Analytical Hierarchical Process of Data Envelopment Analysis (DEAHP) to evaluate the suppliers in a green supply chain. To reduce the damage to the environment, Shin et al. [14] developed their own research model. Lee et al. [15] examined the effects of strategic risk analysis on outsourcing ICT services in California hospitals from 1997 to 2007. The results of the research showed that outsourcing risk analysis has a positive and significant effect on productivity.

Nowadays, it is essential for companies to select the right suppliers to create a space in the business environment. Therefore, choosing a supplier is an important issue for companies. Wan et al. [16] examined a type of supplier selection problem with two-level criteria and proposed a hybrid method that was a hybrid ANP and ELECRE II method. According to the Abdel-Basset study, companies are likely to respond well to unexpected events by considering and applying the appropriate risk reduction strategy [17].

Subsequently, uncertainty and ignorance, in reality, are the key factors that make it challenging to control risks. Hence, risk analysis, reduction, and control provide recommendations for appropriate decision-making. Lo et al. [18] presented a model for obtaining the weight of benchmarks and a modified fuzzy TOPSIS for calculating supplier ratings. This study used the fuzzy MODM model to assign the order to eligible suppliers. The important point in this paper is that this study used the TOPSIS technique and fuzzy theory to strengthen the analytical model due to the uncertainty of managers' opinions. After consulting with company executives, four objective functions are defined: cost, delivery performance, product quality, and total profit. Tong et al. [19] proposed the PROMETHEE II for evaluating the sustainability of the suppliers. They implemented the proposed method for a variety of small- and medium-sized enterprises in China. Liu et al. [20] assessed a new multicriteria decision-making method, which considers the bidirectional influence relation of the criteria, consensus, and the psychological factors of decision-makers. They implemented this method for evaluating emergency medical suppliers.

As mentioned in the literature review, most of the research in the field of supply chain outsourcing is based on chain efficiency and the logic of the research method of data envelopment analysis to evaluate the performance of suppliers, or most of them are selected by selecting indicators.

The research gap observed in the supply chain research is related to the lack of a comprehensive approach for optimizing supplier evaluation as well as order allocation. To cover this part of the research gap, the fuzzy Delphi and BWM methods have been used to evaluate and select the most effective components using expert opinions. Another research gap observed in the research is the non-application of uncertainty conditions in decision-making. In this regard, a robust counterpart formulation is proposed to find optimal order allocation under demand uncertainty.

3. Methodology

In this research, the evaluation and selection of suppliers to supply the required items are made in two stages. In the first stage, the initial evaluation of potential contractors is done, and the desirable and qualified contractors are included in the list of qualified ones. In the second stage of the main evaluation, to determine the volume of supply and order from each final supplier, in this stage, the multi-objective decision-making method is used, and then the multi-objective decision-making model is used to optimize and assign the order to suppliers, which is the main focus of the present study. Figure 2 shows the development framework of the combined MCDM and MODM model in this research.

In the first stage, searching reputable scientific sites and reviewing existing scientific texts on criteria and indicators, evaluation, and selection of suppliers were performed. After selecting the criteria, managers and experts in the fields of procurement, procurement, quality, research and development, and engineering were asked to rate each index according to the importance of the indicators, and on a fuzzy

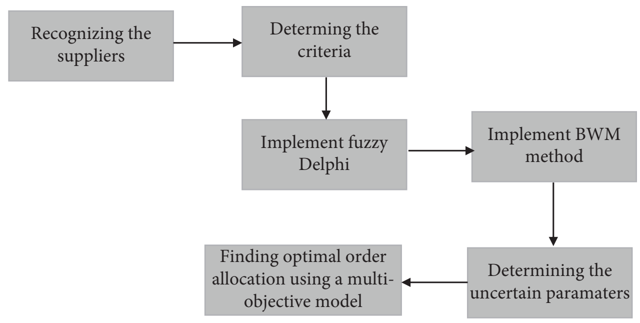

Figure 2: The proposed framework based on MCDM and MODM to evaluate the suppliers.

scale based on the fuzzy calculating the average scores, the indicators that had an average score of "above 3" were identified and selected. In order to receive the opinions of experts, the number of samples should be determined based on the number of the existing community of experts; in this study, due to the limited number of members, the counting method was used, and the opinions of all of them were used.

In order to obtain the necessary assurance from the accuracy and validity of the opinions received from the experts, the reliability test is implemented. In this research, an integrated model has been developed to analyze and select the most appropriate suppliers. The proposed model is a hybrid model that takes into account different ideas while considering different criteria. The proposed model evaluates the suppliers of raw materials, taking into account various constraints (including existing constraints and systemic constraints), and finally assigns the optimal order assignment to each of them.

The research method can be divided into two main parts. The first part involves setting quantitative and qualitative criteria and using the fuzzy Delphi and BWM techniques to weigh the criteria and evaluate the suppliers. The second part is to identify the application and system constraints and combine the results of the first phase with the mathematical model in order to assign the optimal order quantity to each supplier.

3.1. Screening Indicators Based on the Fuzzy Delphi Method. At this stage, using the fuzzy Delphi technique, the indicators are refined and selected. The Delphi expert panel is a mix of 15 experts. Although experts use their mental faculties and abilities to make comparisons, it should be noted that the process of numerical quantification does not fully reflect human thought. The use of fuzzy sets is more compatible with linguistic and sometimes ambiguous human explanations, and hence it is better to use fuzzy numbers to transform mental and linguistic concepts into small quantities in the real world. In this study, triangular fuzzy numbers have been used to convert mental and linguistic concepts into quantitative values.

A fuzzy number is a specific fuzzy set as $\tilde{A} = x \in R/\mu\_\tilde{A}(x)$ in which x accepts the real values of the member of the set R and its membership function is $\mu_{\tilde{A}}(x)$.

Table 1: Verbal fuzzy numbers.

Fuzzy number	Verbal phrase
(0.25, 0, 0)	Very low importance
(0.5،0.25, 0)	Low importance
(0.25, 0.5, 0.75)	Medium importance
(0.5,0.75,1)	Very important
(0.75, 1, 1)	Very important

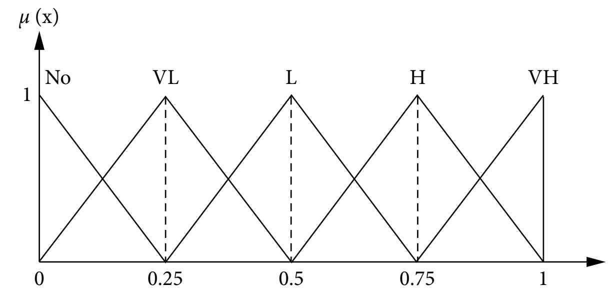

Figure 3: Triangular fuzzy numbers for verbal phrase.

A triangular fuzzy number A is defined by (1) with the membership function of linear fractions $\mu_{\tilde{A}}(x)$.

$$\mu_x(x) = \begin{cases} \dfrac{(x-l)}{(m-l)} l \le x < m, \\ l\, x = m, \\ \dfrac{(u-x)}{(u-m)} m < x \le u, \\ 0 \text{ otherwise}, \end{cases} \quad (1)$$

where l represents the lower bound, m represents the most probable state, and u represents the upper bound and can be represented as a triangular fuzzy number (l, m, u).

In this research, verbal variables have been fuzzy to determine the importance of indicators according to the triangular fuzzy numbers in Table 1 and Figure 3.

After collecting the data, the fuzzy mean of the n respondents' comments is calculated using the usual methods. Then, decompression operations and determining the importance of the indexes are used, and the indexes with a value lower than the average value are removed.

3.2. Validity of the Identified Indicators for Analyzing the Suppliers. To evaluate the validity of the indicators, the Lavoshe method has been applied. In order to calculate this index, the opinions of experts in the field of test content were used, and by explaining the test objectives to them and providing operational definitions related to the content of the questions, they were asked to rate each question based on Likert's three-part spectrum. "Is necessary", "item is useful but not necessary," and "item is not necessary". Then, according to (2), the content validity ratio is calculated.

Table 2: Minimum acceptable CVR value for content validity.

CVR	Number of experts	CVR	Number of experts	CVR	Number of experts
0.37	25	0.59	11	0.99	5
0.33	30	0.56	12	0.99	6
0.31	35	0.54	13	0.99	7
0.29	40	0.51	14	0.75	8
		0.49	15	0.78	9
		0.42	20	0.62	10

$$\text{CVR} = \frac{N_e - N/2}{N/2}, \tag{2}$$

where N is the total number of specialists and Ne is the number of specialists who have selected the necessary option. Therefore, based on the number of experts who evaluated the questions, the minimum acceptable CVR value is calculated based on Table 2. The amount of CVR calculated for them should be less than the desired amount, according to the number of experts evaluating the question, because according to the index, they do not have acceptable content validity and should be excluded from the test.

3.3. Evaluation of the Suppliers Using the BWM Method. The best-worst method is used to solve multi-criteria decision-making problems. The steps of the BWM method to obtain the weight of the criteria can be described as the following steps:

Step 1: Specifying the set of criteria: In this step, the criteria $\{C_1, C_2, \ldots, C_n\}$ that should be used in the decision are considered.

Step 2: Identifying the best and worst criteria.

Step 3: Determining the performance of the best benchmark against other ones using numbers between 1 and 9. The results of the best criterion compared to the other criteria are in the form of equation (3);

$$A_B = a_{b1}, a_{b2}, \ldots, a_{bn}. \tag{3}$$

where a_{bj} indicates the performance of the best criterion (B) relative to criterion j. Obviously $A_{bb} = 1$.

Step 4: Determining the performance of all criteria for the worst case using numbers 1 to 9. The formula for the results of comparisons of criteria to the worst criterion can be defined as equation (4):

$$A_w = a_{1w}, a_{2w}, \ldots, a_{nw}. \tag{4}$$

where a_{jw} indicates the performance of criterion j relative to the worst criterion (W). Obviously, $A_{ww} = 1$.

Step 5: Finding the optimal weights: The optimal values for the criteria are unique, which I will have for each pair of W_j/W_w and W_B/W_j (equation (5)):

$$\begin{aligned} \frac{W_B}{W_j} &= a_{Bj}, \\ \frac{W_j}{W_w} &= a_{jw}. \end{aligned} \tag{5}$$

Table 3: The notation of the proposed mathematical model.

W_j	The weight of goal j
d_j^-	Negative deviation from goal j
d_j^+	Positive deviation from goal j
b_j	The defined level of goal j
A	The weighted sum of deviations from goals
α	Penalty for non-compliant production of suppliers
β	Delivery schedule penalty
a_{ji}	Technical coefficients
Z_j	Maximum (minimum) value of the goal j
C_i	Price of raw materials supplier i
R_i	The cost of transporting the product of the supplier i
K_i	Supplier i capacity
$\widetilde{D}$	Total company demand (under uncertainty)
L_i	Timely delivery point of supplier i
F_i	After-sales service of supplier i
Fl_i	Level of flexibility in improving the quality of the supplier i
x_i	Order quantity from supplier i

To satisfy these conditions for all j, a solution must be provided that minimizes the absolute value of the maximum difference. Given that the weights are non-negative and summable, the problem is expressed as a nonlinear model according to (6):

$$\begin{aligned} &\text{Min}\, \varepsilon^* \\ st:\ &\left|W_B - a_{Bj} W_j\right| \le \varepsilon^*, \quad \forall j, \\ &\left|W_j - a_{jw} W_w\right| \le \varepsilon^*, \quad \forall j, \\ &\sum_j W_j = 1, \\ &W_j \ge 0; \quad \forall j. \end{aligned} \tag{6}$$

After solving the above model, the optimal values of weights ($W_1^*, W_2^*, \ldots, W_n^*$), and the value of ε^* will be obtained. Then, using ε^*, a compatibility rate is introduced, and it will be determined that larger values for ε^* will lead to higher compatibility rates and lower reliability of the comparisons. Finally, the value of the compatibility rate is obtained using ε^* and the related compatibility index is obtained using (7):

$$CR = \frac{\varepsilon^*}{CI}, \tag{7}$$

where CR represents the value of the compliance rate and CI represents the corresponding compliance index. An incompatibility rate less than 0.1 would be desirable.

3.4. Mathematical Model of Order Allocation to the Suppliers. After evaluating the suppliers and selecting them, in this step, using the ideal planning method and mathematical model, the volume of orders is allocated, which is uncertain. The corresponding symbols are defined according to Table 3.

It must be purchased from different suppliers to supply the required raw material. In purchasing from these suppliers, their important features in modeling should be considered. Moreover, the company should be restricted from purchasing from any of the suppliers. For example, the product of each of the suppliers has positive and negative qualitative characteristics that try to include the important characteristics in the proposed mathematical model. The objective function (8) minimizes the distance of the goals from the defined ideal value, and the ideal constraint will keep the value of each goal close to the ideal.

$$\text{Min } A = \sum_{j=1}^{m}\left(w_j d_j^- + w_j d_j^+\right),$$
$$st\colon \sum_{i=1}^{n} a_{ji}x_i + d_j^- - d_j^+ = b_j \quad \forall\{j = 1, 2, \ldots, m\}, \forall\{i = 1, 2, \ldots, n\}. \tag{8}$$

The constraints of this model can be divided into ideal constraints and systemic constraints. Ideal constraints include raw material purchase price, on-time delivery, flexibility in quality improvement, shipping cost, and quality. One of the important limitations, according to the analysis of this unit as well as the interviews conducted with the management, supply of materials, is the limitations of demand. Moreover, the important constraint of the supplier is the production capacity. All the mentioned constraints are entered into the model in the form of mathematical expressions.

(1) Purchase price: Considering that the amount of raw material supplied by the supplier i is equal to x_i and the price of the raw material supplied by the supplier i is equal to C_i, the ideal limit of the purchase price of the raw material is as equation (9).

$$\sum_{i=1}^{n} \alpha c_i x_i + d_1^- - d_1^+ = Z_1. \tag{9}$$

(2) Deliver time: Depending on the delivery time of each supplier's raw material, the ideal delivery time formulation should be minimized. If the delivering time score of the i-th supplier is indicated by L_i, then the delivery limit seeks to minimize all deviations from the delivery time which is shown in equation (10).

$$\sum_{i=1}^{n} \beta L_i x_i + d_2^- - d_2^+ = Z_2. \tag{10}$$

(3) After-sales service: One of the organizations' most important competitive advantages is to enable them for after-sales service. Suppliers' after-sales service allows the organization to increase customer satisfaction and respond to quality complaints. Therefore, organizations should try to select suppliers that maximize after-sales service. If we denote the level of flexibility in the volume of the i-th supplier by F_i, then the after-sales service constraint seeks to maximize the level of flexibility required in the optimal value shown in equation (11).

$$\sum_{i=1}^{n} F_i x_i + d_3^- - d_3^+ = Z_3. \tag{11}$$

(4) Flexibility in quality improvement: Considering that the raw material must be in accordance with the necessary technical and quality conditions, suppliers need to have the necessary flexibility in order to achieve the required technical and quality conditions; this can be a criterion also influenced by the selection of suppliers. If we denote the level of flexibility of supplier i in quality improvement with FL_i, then the limit of flexibility in quality improvement seeks to minimize all deviations from the flexibility of the suppliers, which is shown in equation (12).

$$\sum_{i=1}^{n} Fl_i x_i + d_4^- - d_4^+ = Z_4. \tag{12}$$

(5) Shipping cost: Considering the purchased quantity from the supplier $i\,(x_i)$ and the shipping cost of each ton of product of the supplier $i\,(R_i)$, the ideal limit of shipping cost is defined as equation (13).

$$\sum_{i=1}^{n} R_i x_i + d_5^- - d_5^+ = Z_5. \tag{13}$$

(6) Quality: Considering that suppliers must have the necessary quality to be able to attract the customer, this criterion can also be influenced in the selection of suppliers. If we denote the quality level of the supplier i by Q_i, then the quality constraint seeks to minimize all deviations from the quality of the supplier, which is shown in equation (14).

$$\sum_{i=1}^{n} Q_i x_i + d_6^- - d_6^+ = Z_6. \tag{14}$$

Supplier capacity constraints, raw material demand constraints, and non-negative variables' constraints were also defined as factors involved in the process as follows and added to the model. In this research, customers' demand is considered as an uncertain parameter. The reason for considering this uncertainty is the instability of the demand in most of the supply chains. In addition, supplying raw materials for production has a component of uncertainty in demand. Therefore, uncertainty in the amount of materials required is added to the model with the help of robust planning and an approach based on Bertsimas and Sim [21–23]. Therefore, the volume of demand required will be modified based on the Bertsimas and Sim robust approach [21–23].

$$
\begin{aligned}
& x_i \leq K_i, \\
& \sum_{i=1}^{n} x_i \geq \widetilde{D} + \Gamma p + \sum_{i=1} q_i, \\
& p + q_i \geq \widehat{D} \quad \forall i \in I, \\
& x_i, d_j^-, d_j^+ \geq 0.
\end{aligned} \tag{15}
$$

The proposed model is developed based on the BWM method with the GP method, which is first evaluated based on the BWM method, and finally, using the GP method, the demand and order allocation to suppliers is optimized.

4. Numerical Results

After data collection, data analysis was performed using multi-criteria decision-making techniques, the fuzzy Delphi method, simulation logic, and mixed linear program optimization, compatible with the research method and the type of variables.

Based on the review of library articles and resources, a comprehensive list of 39 criteria of supply chain ranking indicators based on executive risks was introduced. Then, in order to finalize the criteria for selecting suppliers, their validity was evaluated through interviews with 15 experts by Roche Lavoche. Therefore, the most important indicators in the studied industry were introduced from among the found indicators, and suppliers were ranked according to the selected criteria.

According to the evaluation made in the first stage regarding the content validity of the research, out of the 39 identified indicators, only 25 indicators were approved (indicators with CVR values less than 0.49 are rejected), and in the next stage, screening, indicators by the fuzzy Delphi method were addressed. In the analyses performed, the deviation of experts' opinions is 0.07, which is appropriate in terms of the deviation of opinions, and good consistency is established. Table 4 presents the final refined indicators from the 39 identified indicators.

Next, the views of seven experts to assess the importance of the indicators identified in the field of the supply chain were examined through pairwise comparisons. It is worth mentioning that the fuzzy Delphi process has been performed in two stages because the rate of incompatibility of the comments was less than 0.1; hence, the validation of the comments has been approved. Finally, based on the evaluations made in the first step of screening, out of the 25 refined indicators, 11 indicators ($C1$, $C7$, $C8$, $C10$, $C11$, $C12$, $C18$, $C19C$, $C22$, $C23$, and $C24$) are selected.

4.1. Evaluating the Suppliers Using the BWM Approach.

In order to evaluate the suppliers, according to the identification of the characteristics of the organization, the effective criteria in the evaluation of the suppliers were ranked. For this purpose, in the first step, 11 indicators specified in the previous step based on the method

BWM were examined. In the second step, according to a survey of organizational experts, the $C1$ index was evaluated

Table 4: Indicators in the supply chain and supplier selection.

$C1$	Changes in exchange rates
$C2$	Change in interest rates
$C3$	Policy changes and tariffs
$C4$	Political change
$C5$	Changing consumer tastes
$C6$	Natural disaster
$C7$	Product reliability
$C8$	Shipping price
$C9$	Credibility and past performance
$C10$	Quality system support
$C11$	Compliance with safety/environmental regulations
$C12$	Flexibility in volume
$C13$	Production technology level
$C14$	Proximity of relationships
$C15$	Transparent communication
$C16$	Business maturity level
$C17$	Extra expenses
$C18$	Environmental programs and controls
$C19$	Existence of quality systems and continuous improvement
$C20$	Waste management
$C21$	Flexibility in product mixing
$C22$	Delivery reliability
$C23$	Ability to develop technology
$C24$	Ease of communication
$C25$	Consolidation of communications

as the best (most desirable, most important) and the $C22$ index as the worst (most undesirable, least important) criteria. In the third step, the importance of the best and worst criteria compared to other criteria was evaluated based on the opinions of key experts, and the geometric mean of the results of pairwise comparisons is shown in Table 5.

In the next step, the relationships between the criteria were developed in accordance with what is common in the BWM method, and the relevant model was planned and implemented in Lingo software. After solving the model, the optimal weight of the criteria as well as the value of the objective function (ε) is illustrated in Figure 4.

4.2. Order Allocation to Suppliers.

According to the conditions of the organization under study, first, the supply chain processes were examined, and in this study, the supply situation of raw materials was evaluated. The results of this analysis indicated the existence of multiple suppliers for the supply of raw materials. In this route, the means of transportation according to the planning done by following the system (FIFO) to the place of suppliers and the level of demand required by the company are received. Therefore, the vehicles carry out the process of loading the raw materials according to the planned capacity and then return to the place of production. After weighing the indicators and identifying the constraints, the ideal planning model can be implemented in order to allocate the volume of demand (so that the importance of the criteria in supply can be applied as weights corresponding to the decision-making preferences), and it provides the basis. Table 6 shows the information on raw materials and suppliers.

In the ideal planning model, the ideal values are specified for each of the goals, and then the answer to the problem is

Table 5: Pairwise comparisons of the best and worst criteria based on the opinions of key experts.

Criteria	C1	C7	C8	C10	C11	C12	C18	C19	C22	C23	C24
Best	1	3.6	4.2	3	5.4	4.8	6.2	4	4.6	4.8	4.4
Worst	4.2	4.3	5.1	4.2	6.2	4.7	6.2	4	1	5.2	4.7

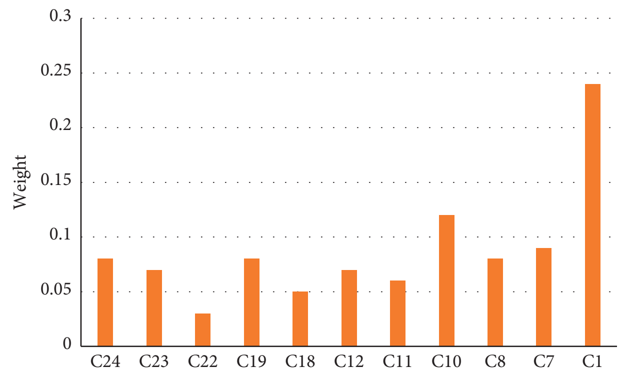

Figure 4: The optimal weight of criteria determined by the BWM.

Table 6: Details of the suppliers of raw materials.

Suppliers	Purchase price	Delivering time	After-sale service	Flexibility	Transportation cost	Quality cost	Capacity
Supplier 1	2.5	0.4	0.303	0.147	0.088	2300	4500
Supplier 2	2.41	0.256	0.259	0.369	0.295	2000	3600
Supplier 3	2.45	0.074	0.152	0.209	0.294	2100	2800
Supplier 4	2.35	0.135	0.229	0.096	0.318	1500	3300
Supplier 5	2.53	0.135	0.057	0.18	0.184	1400	3100

Table 7: Ideal values for set goals.

Criteria	Cost	Delivery time	After-sale service	Flexibility	Transportation cost	Quality
Objective value	28912	2856	11025	3192	2808	15890000

specified in such a way that the distance between the criteria and the goals is minimized. Due to the specified limitations, the values listed in Table 7 were considered as the goal for each goal.

Suppliers' prioritization of criteria is shown in terms of weights. These weights were placed as coefficients of variables in each ideal constraint that represents a goal, and at the same time, using the weights obtained from prioritizing the criteria in the model, each corresponding deviation was assigned its corresponding weight. System constraint parameters were also obtained by observing, interviewing, and reviewing information collected from different units of the company. This model was programmed and solved using LINGO software, the results of which are shown in Figure 5. As can be seen, orders have been assigned to different suppliers for the supply of materials, which is the result of the total purchase corresponding to the preferences of the decision-maker.

In this case, because of the ideal amount of price targets, timely delivery, flexibility in volume and quality improvement, transportation, and quality, the optimal amount is

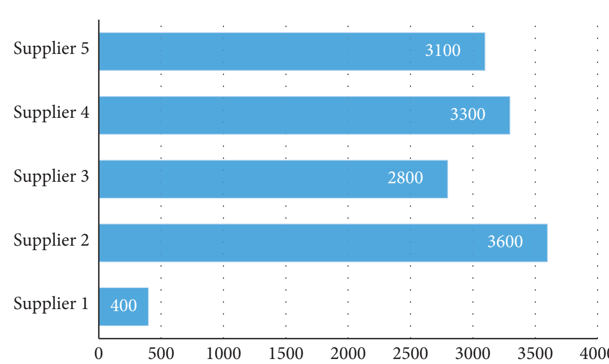

Figure 5: Optimal order allocation to suppliers.

defined; the increase of the ideal does not make sense, and hence for positive criteria (such as quality) only a reduction of the ideal and for negative criteria (such as price) only an increase of the ideal is undesirable.

5. Concluding and Future Directions

In today's global competition, economic and manufacturing firms have turned to supply chain management in order to gain a competitive advantage in order to gain more market share. The key issue in a supply chain is the coordinated management and control of all activities. Choosing a supplier is one of these issues, which is one of the most important strategies for the company to gain a competitive advantage. One of the most important reasons for highlighting the role of supplier selection for organizations is the shift of a paradigm. While companies initially sought to increase their supplier list in order to increase their bargaining power over prices, they are now trying to reach out to fewer suppliers that best meet their needs, i.e., establish a strategic alliance. This increases the efficiency and effectiveness of the company and its value chain through partnership communication and facilitating communication, providing faster and higher quality items. In this study, an approach based on decision-making policies was introduced to select suppliers and allocate order volume to them. Therefore, based on the evaluation, 39 key indicators for supplier evaluation were identified and based on content analysis, 25 key indicators were screened based on the Lavache method. According to the analysis, it was shown that the company has a variety of suppliers and needs to analyze key indicators such as exchange rate fluctuations and ease of communication. Then, based on the fuzzy Delphi method, among the 25 key indicators, 11 effective indicators in the study organization entitled "Exchange rate changes, product reliability, shipping price, support system quality, compliance with safety criteria, flexibility in volume, programs and environmental controls, quality system, delivery reliability, technology development capability, and ease of communication" were selected. Based on the calculations of the BWM method, it was shown that the exchange rate change with a weight of 0.24 is the most important factor, and the quality component of the support system with a weight of 0.12 was the second important factor.

Accordingly, it can be concluded that the issue of concern about exchange rate fluctuations and the quality of products supplied is a vital issue for the company under study, which should be well considered for the selection of suppliers. Furthermore, based on the multi-objective mathematical model, the inventory level required by suppliers was determined based on the optimization policy. According to the results obtained in the study, it was shown that in order to maintain the resilience of the company's supply chain, the total required demand is distributed among the five suppliers, and "Supplier No. 2" with 3600 units has the highest allocation and "Supplier No. 1" with 400 Units had the lowest amount of raw material allocation.

In this research, the managerial insights can be analyzed from several dimensions. First, it is considered that different indicators are applied in evaluating suppliers, which can help supply chain managers evaluate their suppliers from different aspects. Moreover, ranking suppliers and assigning orders to them simultaneously is a comprehensive approach to decide for supplying raw materials, which reduces any errors in decision-making. Therefore, this research can be used as a basis for managing relationships with suppliers in different supply chains. On the other hand, during the different stages of this research, new points were discovered, and at the same time, with the progress of this research, more ambiguities were created for researchers, which due to the existing limitations require more research. Finally, for the research of future researchers who intend to work in this field, some topics are suggested.

(1) To increase the accuracy and reduce uncertainty in prioritizing criteria and suppliers and assigning the optimal order amount to each supplier, it is suggested to combine this model with neural network models and genetic algorithm and compare it with the results of this study.

(2) Indicators of this research have been compiled according to the scope of research and appropriate to the company under study. It is suggested to provide a comprehensive model related to similar organizations and large companies by examining other similar companies.

(3) It is suggested that the indicators based on the conceptual model or structural model be hypothesized in similar companies to identify the supply management framework.

Data Availability

All data are available as a table in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A Multiobjective Mathematical Model for Truck Scheduling Problem in Multidoor Cross-Docking System

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Cross-docking is the main operation of unloading products from incoming trucks, regrouping products in relation to their destination, and loading directly onto shipping trucks, reducing warehousing, picking, transportation costs, and delivery times. This is the intended logistics technology. In this paper, we present a new bi-objective mixed-integer mathematical model for truck scheduling problems in cross-docking systems. The goal of the proposed mixed-integer mathematical model is to minimize the total operation time (makespan) and cost of moving cargo within the terminal. The performance of the proposed model is compared with that of the available model to solve small instances. The results showed that in solving small size of problem, the proposed model in this study is more efficient and we found better solutions. An evolutionary algorithm called the nondominated sorting genetic algorithm (NSGA-II) has been proposed to solve larger instances due to computational complexity. To evaluate the proposed algorithm, a comparative analysis of benchmark instances was performed and the efficiency of the above algorithm was compared to the nondominated ranked algorithm (NRGA) based on the index designed in the literature. The statistical hypothesis testing (t-test) is used for determining the best algorithm based on the average runtime and average number of Pareto solutions. Using the Taguchi method, the proposed algorithms are tuned. Considering a temporary storage space and the multiple receiving and shipping docks is the main contribution of the paper. Finally, for evaluating algorithms, multicriteria decision-making (MCDM) technique and statistical method are used. The results show the suitable performance of presented model.

1. Introduction

Logistics costs have been the focus of all manufacturing and distribution companies for the past decade [1]. Companies are facing increasing pressure to reduce inventory and lead times and improve global efficiency. Logistics costs can be divided into three categories: inventory (including warehousing), transportation, and management costs, but transportation costs are the more influential part [2]. However, cross-docking is an approach that eliminates the two most costly processing operations of storage and picking [3]. Moreover, since approximately 30% of costs of each product are related to distribution process, numerous firms are attempting to develop their distribution strategies to achieve an effective flow management [4]. This paper is concerned with the introduction and modeling of a novel method in distribution system management that has attracted increasing attention in today's world. Cross-docking is a relatively new technique in supply chain operations that consists of transferring cargo directly from inbound trucks to outbound trucks without intermediate storage [5]. The main objectives of implementing such a strategy are to reduce inventory levels and associated processing costs and integrate truck loading into the total truck loading, especially by reducing lead times for service levels and customer satisfaction. It is to improve the degree. Finding the best sequence of inbound and outbound of trucks reduces system operation and costs, and it is blindingly obvious that this primary issue happening continuously in daily operation in cross-docking has a huge impact on the fast-moving process. Solving the problem of truck scheduling in cross-docking, which is one of the most important extent issues in cross-docking system, is the issue of this research. In cross-docking, if the goods are to be stored, this will be possible for a very short time and up to 24 hours. This will reduce the time required to meet customer demand, inventory maintenance costs, and required space for storage. Generally, cross-docking is used when goods cannot be shipped directly. Operations generally performed in a cross-docking include [6]the following:

(i) Scheduling shipments to deliver goods from producers to cross-dock. It is required that goods deliver to cross-dock in accordance with specific time in scheduling, which is linked to shipping time.
(ii) Incoming goods are immediately sorted by demands of destinations. Outbound trucks can load and transport a combination of inbound goods and goods in a temporary storage location. A high degree of cooperation and coordination is needed to prevent any unwanted delays.
(iii) Orders (goods) move quickly to the shipping dock.

Compared with traditional docking, activities such as receiving inspection, storing, assembly, and ordering have been eliminated. Figure 1 shows the general operation of a cross-docking.

The following criteria can be considered as the cross-docking performance criteria [8]:

(i) The number of receiving and shipping docks required
(ii) Dock utilization
(iii) Average time of unloading and loading of trucks
(iv) Total time spent moving materials from receiving docks to shipping docks
(v) Total time required to perform cross-docking operations
(vi) Cost of moving and maintaining inventory

Depending on what type of strategy is being adopted concerning the facility and operating conditions, it is possible to define different models of cross-docking. Deciding on the quantity and quality of the following factors produces different combinations of models:

(i) The number of available docks in site
(ii) Pattern of entry and exit of trucks to docks (dock holding pattern)
(iii) The presence or absence of temporary storage

The cross-docking model scrutinized in this paper is one of the 32 models presented in [8] with separate receiving and shipping docks along with a temporary storage. The dock holding pattern of the trucks is also static and does not include the assumed model of cross-docking operation or distribution center such as scanning, weighing, labeling, and sorting. In addition, it is assumed that the temporary storage place is close to the receiving docks (Figure 2).

The practical applications of truck scheduling are vast and varied and are applicable in a variety of areas, such as software development, planning in major transportation organizations, airlines, post offices, chain stores, and many other areas. From a theoretical point of view, truck scheduling is a very attractive research field for researchers, especially planners. The well-known problem of truck scheduling in cross-dock is one of the problems of hybrid optimization with computational complexity of $O(mn2^m)$ (m number of targets and n population size) [9]. In recent years, researchers' interest and attempt in scheduling trucks in cross-docking have greatly increased, and many new modeling concepts and algorithms have been designed and implemented in this area, but according to expert researchers, there are still many shortcomings in this area, which are being from two aspects [10].

(i) Developing models closer to real issues
(ii) Improving problem-solving methods to enhance the quality of the solution and the problem-solving time

Although the issue of truck scheduling in cross-docking is very important from the practical point of view, perhaps the main reason for these shortcomings is the difficulty of problem-solving and improving the solution methods in enhancing the quality of the solution and improving the time of solving such problems. There are only few attempts to mathematically model the truck scheduling problem with respect to real constraints, and our model is more effective due to its size complexity. Therefore, efforts to address these shortcomings and simultaneously reduce the time and cost of operations by using new method make it necessary to conduct this research.

The goal of this paper was to present a model and study the problem of truck scheduling. When it comes to scheduling issues, total operation time is often referred to as makespan. In this study, makespan is defined as the total uptime for cross-docking operations. Total uptime is the time between the first product of the first scheduled inbound truck being unloaded at the receiving dock and the last product of the last scheduled outbound truck being loaded at the shipping dock. The purpose of this study was to find the best track docking sequence for both inbound and outbound tracks to minimize the total cross-docking uptime (equivalent to maximizing the throughput rate) of the cross-docking process. Product assignments from inbound trucks to outbound trucks are determined at the same time as the inbound and outbound truck docking sequences. The purpose of the problem is to reduce the total time to complete the operation and minimize the total costs of transshipment in the cross-docking. One of the most important advantages that has attracted a lot of attention to cross-docking is the characteristic of this method to reduce costs in the distribution system. In this study, minimizing the cost of transshipping goods is considered as one of the objectives of the model.

The rest of this paper is organized as follows. Section 2 summarizes some proposed papers applied in the case of truck scheduling in cross-docking systems. Section 3 briefly describes the mathematical model. This model serves as a

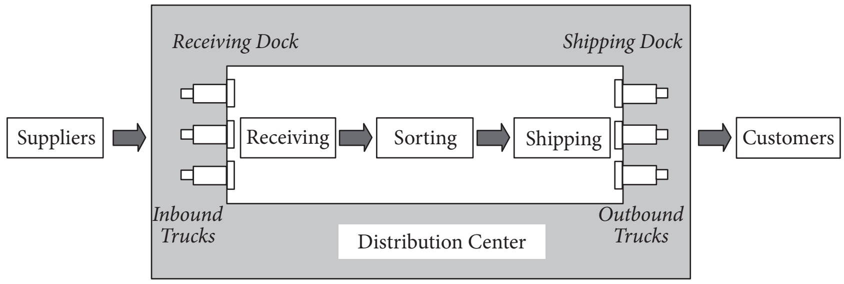

Figure 1: General cross-docking operation [7].

Receiving area		Temporary storage	Shipping area	
Number of docks	Dock holding pattern		Number of docks	Dock holding pattern
Multiple	Stay	Yes	Multiple	Stay

Figure 2: Studied cross-docking model [8].

foundation for the heuristics and is also used to evaluate their performance to the best solution. Section 4 presents the heuristics used for the resolution of the problem. Section 5 addresses parameter setting and a method called the Taguchi plan in this case. Section 6 deals with the computational results and implementation of the algorithms, and finally, Section 7 is the conclusion and trends for future work.

2. Literature Review

The objective of this section is to analyze the existing literature in order to understand the problems and try to find the respective proposed approaches. Reference [10] reviewed and classified the literature of scheduling trucks in cross-docking. An important point is the strategic issues and operations that need to be paid attention and addressed in the cross-docking system life cycle, such as cross-docking location, design and layout of warehouse, transshipping routing, and warehouse resource planning, which, to further study on this area, one can refer to [3]. Since the issue of cross-stocking has attracted increasing attention in recent years, [11] undertook a wide-ranging study to identify the research gap between theoretical issues and real-world application challenges that reveal these differences. The most famous model for truck scheduling in cross-docking system presented by [7]investigated a cross-docking system in which a temporary storage buffer is located beside the shipping dock. The purpose of this study was finding the best scheduling sequence for both receiving and shipping trucks in receiving and shipping docks to minimize total operation time or increase the efficiency of cross-docking system. Some studies such as [12–14] try to develop the [7] mathematical model by considering different objectives such as earliness and tardiness or with different solving methods such as metaheuristic. There are few studies in the literature that have introduced the mathematical model for truck scheduling in multi-door cross-docking system. For instance, [15] presented a new mixed-integer programming model that is more efficient than the model presented by [7] and to demonstrate the efficiency of their model for large-scale problems used the hybrid heuristic algorithm for collective optimization of birds with a refrigeration simulation algorithm. Reference [16] describes a Lagrangian heuristic algorithm for a transit problem, where certain quantities of certain products must be transferred directly from a certain group of incoming trucks to a certain group of outgoing trucks. The goal is to plan activities and design transit plans, while minimizing the end time of the entire process. The main contribution of the paper is the Lagrangian decay diagram for the structured integer linear model of the problem. Reference [17] studied the problem of sequencing multiterminal trucks in a cross-connected hub with the aim of minimizing production time, and they came up with a parallel machine scenario. Instead of the traditional stream stores setup and proposes a polynomial parallel machine-based heuristic method that outperforms time-indexed math formulas and modern heuristics for small, medium, and large cases big (Shahmardan and Sajadieh [18], they proposed simulated annealing as a solution method. Reference [19] first proposed a mixed-integer linear programming model to optimally solve small instances. Next, two heuristics are proposed to solve the two problems in an integrated manner. These heuristics are as follows: vehicle routing cross-docking heuristic (VRCDH) and cross-docking vehicle routing heuristic (CDVRH) each focuses on one of the issues. On the other hand, among the recent studies, [20] can be mentioned that they assumed that freight trucks during their operations fail and the number of truck failures in a given period follows the Poisson distribution. They also set a deadline for each truck and used three heuristic algorithms to solve their two-objective model with the goal of reducing the number of delayed trucks and completing them and finally comparing the results of the three algorithms. Reference [21] introduced eight mixed-integer mathematical programming models for modeling the problem of door (dock) allocation to destinations in cross-docking environments and compared and introduced the best and most efficient models based on the standard examples available in the problem literature. Rashidi Komijan et al. [22] presented a school bus cross-dock and routing problem. The main contribution of their paper was considering gender separation. Minimizing the transportation costs was the main objectives of their research. Khanchehzarrin et al. [23] presented a model for the time-dependent vehicle routing problem. Considering traffic condition is the main contribution of their paper. Reference [24] also presented two complex integer mathematical models for allocation door (dock) problem with the purpose of reducing displacement costs they used the generation columns algorithm to solve the models. The manner of waiting trucks to arrive the docks is one of the important issues studied by [25], and using the M/M/1 queueing theory model, remaining time for trucks was minimized; also, a two-objective model with the goals of reducing the cost of goods storage and reducing energy consumption in-warehouse transporters was presented and solved by two competing algorithms, Marguerite and gray wolf optimizer. Reference [26] presented a Tabu search approach to the truck scheduling problem with multiple docks. They considered minimizing the total travel time and the total tardiness as an objective [27]. Through a low-cost scheduling strategy, they addressed the issue of scheduling inbound and outbound trucks at the cross-dock facility when the arrival time of the vehicle was unknown. Two metaheuristics, MODE and NSGA-II, were used to solve the designed sampling problem and compare it to the random search-based genetic algorithms present in the literature. Khalili-Damghani et al. [28] presented a model for disaster hub location-allocation problem. The location problem was solved using GIS method, and the allocation problem was solved using the metaheuristic method. Shafipour-Omrani et al. [29] presented the simulation-optimization model for liquefied natural gas transportation. The main contributions of the presented model were considering hub location using the simulation method. The results of their paper show the suitable performance of their model. Reference [30] presented a mathematical model of mixed-integer programming for door assignments and track sequences in multidoor cross-docking systems. The goal of this model was to minimize total uptime or turnaround. Next, modified particle swarm optimization (so-called GLNPSO) with special encoding and decoding schemes was proposed to solve the track scheduling problem in multidoor cross-docking systems. Among the studies that are closely related to the model studied in this paper is [31] that introduced a multi-periodic cross-docking model considering the variable capacity of shipping and varied delivery time for shipping trucks by a complex integer programming and solved the model using an evolutionary computational approach based on a genetic algorithm whose results were compared to branch and case algorithm to evaluate the efficacy of the method. The difference between the above study and the model presented in this paper is to consider the temporary storage location in the mathematical model, as well as the multiple receiving and shipping docks of the trucks. Moreover, a multiobjective mathematical model presented in this paper includes reducing total operational time and costs of transporting inside the terminal. To solve the problem, nondominated storing genetic algorithm (NSGA-II) and nondominant ranked genetic algorithms (NRGAs) are applied and the results of two algorithms were compared and analyzed to identify a more effective algorithm. According to studies in the literature, considering a temporary storage space and the multiple receiving and shipping docks has a great effect on the efficiency of the model; therefore, it is necessary to address these shortcomings and bring the issue closer to the real situation. The literature review is shown in Table 1.

3. The Model

3.1. Indices

i Receiving truck indices

j Shipping truck counter

k Merchandise counter

m Receiving dock counter

n Shipping dock counter

R The number of receiving trucks

S The number of shipping trucks

M The number of receiving docks

N The number of shipping docks

P Types of goods

3.1.1. Parameters

$\mathbf{p}^{\mathbf{r}}_{\mathbf{ik}}$ The number of k-type goods loaded into the truck i by default

$\mathbf{p}^{s}_{jk}$ The number of k-type goods must be loaded into the truck j

h_k Time of loading (unloading) for the k-type good

W_{mn} Time of transshipping of goods from the receiving dock m to the shipping dock n (for any quantity of goods of any kind)

w^{fs}_n Time of transshipping the goods from temporary storage to shipping dock n

C^D_k Cost of shipping the k-type good from receiving dock to shipping dock directly

C^{TS}_k Cost of shipping k-type good from the receiving dock to the temporary storage place

C^{FS}_k The cost of moving k-type good from a temporary storage place to a shipping dock

D Replacement time of trucks on docks

Q Very large positive number

x^D_{ijk} The number of k-type goods being transported directly from the receiving truck i to the shipping truck J

x^{TS}_{ik} The number of k-type goods moved from the receiving truck i to the temporary storage location

x^{FS}_{jk} The number of k-type goods moved from the temporary storage location to the shipping truck j

Table 1: Literature review.

Author	Temporary storage space	Multiple receiving and shipping docks	Multiproduct	Time windows	Metaheuristic algorithm
Khalili-Damghani et al. [28]			*		*
Shafipour-Omrani et al. [29]		*		*	
Khanchehzarrin et al. [23]	*			*	
Rashidi Komijan et al. [22]				*	*
Gaudioso et al. [16]		*	*		
Fard and Vahdani [25]	*	*			
Shahmardan and Sajadieh [18]					
Nassief et al. [24]	*		*	*	
Khalili-Damghani et al. [31]	*				*
Wisittipanich and Hengmeechai [30]		*	*		
Heidari et al. [27]		*	*	*	
This research	*	*	*	*	*

3.1.2. Variables

$\mathbf{t_{ij}} = \begin{cases} 1 \\ 0 \end{cases}$ If the good from the receiving truck i is transported to the sipping truck j
otherwise

$\mathbf{p_{ij}} = \begin{cases} 1 \\ 0 \end{cases}$ If the receiving truck i overrides the receiving truck j in the sequence of receiving trucks

otherwise

$\mathbf{q_{ij}} = \begin{cases} 1 \\ 0 \end{cases}$ If the shipping truck i overrides the shipping truck j in the sequence of the shipping trucks

otherwise

$\mathbf{A^r_{im}} = \begin{cases} 1 \\ 0 \end{cases}$ If the receiving truck i is assigned to the receiving dock m
otherwise

$\mathbf{A^s_{jn}} = \begin{cases} 1 \\ 0 \end{cases}$ If the shipping truck j is assigned to the shipping dock ns

otherwise

$\mathbf{Z_j} = \begin{cases} 1 \\ 0 \end{cases}$ If the product is transported from the temporary storage to the shipping truck J

otherwise

$\mathbf{d^r_{im}}$ The time the receiving truck i enters the receiving dock m

$\mathbf{l^r_{im}}$ The time the receiving truck i leaves the receiving dock m

$\mathbf{d^s_{jn}}$ The time the shipping truck j enters the shipping dock n

$\mathbf{l^s_{jn}}$ The time the shipping truck j leaves the shipping dock n

3.2. Mathematical Model

$$\text{Min}\, T, \tag{1}$$

$$\text{Min}\mathbf{C_T} = \sum_{i=1}^{R}\sum_{j=1}^{S}\sum_{k=1}^{P}\left(C_k^D x_{ijk}^D + C_k^{TS} x_{ik}^{TS} + C_k^{FS} x_{jk}^{FS}\right). \tag{2}$$

Subject to:

$$T \geq l_{\text{jn}}^{s}, \quad \forall j = 1, 2, \ldots S, n = 1, 2, \ldots N, \tag{3}$$

$$\sum_{m=1}^{M} A_{im}^r = 1, \quad \forall i = 1, 2, \ldots R, \tag{4}$$

$$\sum_{i=1}^{R} A_{im}^r \geq 1, \quad \forall m = 1, 2, \ldots M, \tag{5}$$

$$\sum_{n=1}^{N} A_{jn}^s = 1 \quad , \forall j = 1, 2, \ldots S, \tag{6}$$

$$\sum_{j=1}^{S} A_{jn}^s \geq 1, \quad \forall n = 1, 2, \ldots N, \tag{7}$$

$$\sum_{i=1}^{R} x_{ijk}^D + x_{jk}^{FS} = p_{jk}^s, \quad \forall j = 1, 2, \ldots S, k = 1, 2, \ldots P, \tag{8}$$

$$\sum_{j=1}^{S} x_{ijk}^D + x_{ik}^{TS} = p_{ik}^r, \forall i = 1, 2, \ldots R, k = 1, 2, \ldots P, \tag{9}$$

$$\sum_{i=1}^{R} x_{ik}^{TS} = \sum_{j=1}^{S} x_{jk}^{FS}, \quad \forall k = 1, 2, \ldots P, \tag{10}$$

$$x_{ijk}^D \leq Qt_{ij}, \quad \forall i = 1, 2, \ldots R, j = 1, 2, | \ldots S, k = 1, 2, \ldots P, \tag{11}$$

$$l^r_{im} \geq d^r_{im} + A^r_{im} \cdot \sum_{k=1}^{p} p^r_{ik}.h_k, \quad \forall i = 1, 2, \ldots R, m = 1, 2, \ldots M, \tag{12}$$

$$d^r_{jm} \geq l^r_{im} + D - Q\left(1 - p_{ij}\right), \quad \forall i, j = 1, 2, \ldots R, m = 1, 2, \ldots M, i \neq j, \tag{13}$$

$$d^r_{im} \geq l^r_{jm} + D - Qp_{ij}, \quad \forall i, j = 1, 2, \ldots R, m = 1, 2, \ldots M, i \neq j, \tag{14}$$

$$\begin{aligned} &d^r_{im} \geq d^r_{jn} - Qp_{ij} - Q\left(1 - A^r_{im}\right) - Q\left(1 - A^r_{jn}\right), \\ &\forall i, j = 1, 2, \ldots R, m, n = 1, 2, \ldots M, i \neq j, m \neq n, \end{aligned} \tag{15}$$

$$\mathbf{p_{ii}} = 0, \quad \forall i = 1, 2, \ldots R, \tag{16}$$

$$l^s_{jn} \geq d^s_{jn} + A^s_{jn} \cdot \sum_{k=1}^{p} p^s_{jk}.h_k, \quad \forall i = 1, 2, \ldots R, m = 1, 2, \ldots M, \tag{17}$$

$$d^s_{jn} \geq l^s_{in} + D - Q\left(1 - q_{ij}\right), \quad \forall i, j = 1, 2, \ldots S, n = 1, 2, \ldots N, i \neq j, \tag{18}$$

$$d^s_{in} \geq l^s_{jn} + D - Qq_{ij}, \quad \forall i, j = 1, 2, \ldots S, n = 1, 2, \ldots N, i \neq j, \tag{19}$$

$$\begin{aligned} &d^s_{im} \geq d^s_{jn} - Qq_{ij} - Q\left(1 - A^s_{im}\right) - Q\left(1 - A^s_{jn}\right), \\ &\forall i, j = 1, 2, \ldots S, m, n = 1, 2, \ldots N, i \neq j, m \neq n, \end{aligned} \tag{20}$$

$$q_{ii} = 0, \quad \forall j = 1, 2, \ldots S, \tag{21}$$

$$\begin{aligned} &l^s_{jn} + Q\left(1 - A^s_{jn}\right) \geq d^r_{im} + W_{mn} + \sum_{k=1}^{p} x^D_{ijk}.h_k + w^{fs}_n \\ &+ \sum_{k=1}^{p} x^{FS}_{jk}.h_k - Q\left(1 - t_{ij}\right) - Q\left(1 - z_j\right) - Q\left(1 - A^r_{im}\right) l^s_{jn} \\ &= \mathrm{Max}\left\{d^s_{jn}, \mathrm{Max}\, t_{ij}.d^r_{im}\right\} + \mathrm{Max}\left\{A^s_{jn} A^r_{im} W_{mn}\right\} \\ &+ Z_j.w^{fs}_n + 2\sum_{k=1}^{p} p^s_{jk}.h_k \\ &\forall i = 1, 2, \ldots R, j = 1, 2, \ldots S, m = 1, 2, \ldots M, \\ &n = 1, 2, \ldots N, i \neq j, m \neq n, \end{aligned} \tag{22}$$

$$\begin{aligned} &l^s_{jn} + Q\left(1 - A^s_{jn}\right) \geq l^r_{im} - Q\left(1 - t_{ij}\right) - Q\left(1 - A^r_{im}\right) l^s_{jn} \\ &= \mathrm{Max}\left\{d^s_{jn}, \mathrm{Max}\, t_{ij}.d^r_{im}\right\} + \mathrm{Max}\left\{A^s_{jn} A^r_{im} W_{mn}\right\} \quad p^s_{jk}.h_k, \\ &+ Z_j.w^{fs}_n + 2\sum_{k=1}^{p} \end{aligned} \tag{23}$$

$$\text{all variable} \geq 0. \tag{24}$$

Constraint equation (1) represents the model's initial goal of minimizing manufacturing margins. Second objective function equation (2). The second purpose is to minimize the total cost of transshipment in the warehouse. Makespan equalizes condition equation (3) with the time the last transport truck leaves the transport dock. Condition equation (4) ensures that each receiving track is associated with only one receiving dock. Condition equation (5) assigns each receive dock to at least one receives track to utilize all receive docks. This constraint applies if the number of receiving docks does not exceed the number of receiving tracks. This is part of the mathematical model assumptions. Similarly, constraints equations (6) and (7) control the allocation of transport trucks to the transport dock. Condition equation (8) specifies the relationship between the products transferred from all receiving trucks and the temporary storage on each shipping truck. In addition, this constraint makes the total of all products shipped from all receiving trucks and temporary storage to shipping trucks equal to the number of products initially required for that shipping truck. Similarly, condition equation (9) specifies the relationship between the products transferred from each receiving truck and the temporary storage on all shipping trucks. This is done by setting the total number of products transferred from each receiving truck and temporary storage to all shipping trucks equal to the total number of products initially loaded on each receiving truck. Constraint equation (10) ensures that the total number of products transferred to the intermediate vault is equal to the total number of products transferred from the intermediate vault. Constraint equation (11) sets the relationship between the product transfer variable and the decision variable *t_ij*. Condition equation (12) sets the time for receiving truck i to leave receiving dock m to be greater than or equal to the time for receiving truck i to enter receiving dock m plus the time it takes to unload all products. This equation is valid only if the receiving track i is associated with the receiving dock m. Constraint equations (13) and (14) adjust the time of entry and exit of different receiving trucks to the same receiving dock based on the order of the receiving trucks. Constraint equation (15) adjusts the arrival times of different receive tracks to different receive docks based on the order of the receive tracks. Condition equation (16) guarantees that the receiving track does not precede in the receiving track order. Constraint equation (17) sets the time it takes for transport truck j to leave transport dock n to be greater than or equal to the time it takes for transport truck j to load all the required products in time to enter transport dock n. This equation is valid only if transport truck j is associated with transport dock n. Constraint equations (18) and (19) adjust the time of entry and exit of different transport trucks to the same transport dock based on the order of the transport trucks. Constraint equation (20) adjusts the admission time of different transport trucks to different transport docks based on the order on the transport truck.

4. Solution Method

Different approaches have been applied to model and solve this problem. These approaches include mixed-integer

Table 2: Makespan obtained by mathematical model for the test problems.

Problem set	Problem size				Exact solution (makespan)	
	Number of receiving trucks	Number of shipping trucks	Number of product types	Total number of products	Optimal [7]	Optimal this study
1	4	5	4	990	1557	1483
2	5	4	6	1030	1577	1412
3	3	3	8	890	1372	1300
4	5	5	8	1000	1749	1503
5	5	3	8	960	1579	1355
6	4	4	5	1020	1546	1370
7	5	4	6	980	1535	1330
8	3	5	7	890	1525	1451
9	4	4	8	900	1473	1334
10	3	4	9	930	1452	1363
11	5	4	6	1620	2232	1791
12	6	4	8	1950	2833	2140
13	5	6	8	1610	2386	1554
14	5	5	8	1680	2385	1831
15	6	5	4	2030	2745	2069
16	5	6	6	1690	2407	2001
17	4	4	7	1180	1867	1397
18	6	6	7	1770	2502	1989
19	5	5	10	1720	2553	2359
20	6	6	9	2020	2732	2392

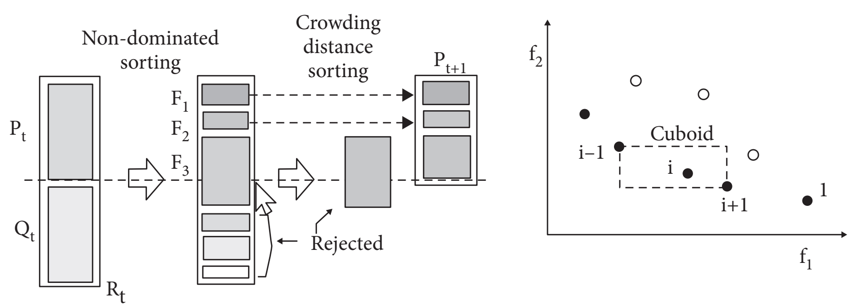

Figure 3: Nondominated sorting genetic algorithm II (NSGA-II).

programming, branch and boundary techniques, search algorithms, full enumeration methods, and heuristic and metaheuristic algorithms. Full enumeration methods and mixed-integer programming have been used as the basic approaches to generate exact solutions, and metaheuristic algorithms have used these solutions to obtain the optimal responses. In the following, we will discuss in detail the different approaches to solve the problem of truck scheduling and studies in the field of cross-docking.

In this study, it is attempted to introduce an effective model that meets the needs of the day, by considering as far as possible the multiple objectives and considering constraints in real circumstance of truck scheduling problem. Twenty sets of test problems were randomly generated to test the performances of the mathematical model. Details on the test problems are presented in [8]. To validate the presented model, it was considered as the single-objective model with the aim of minimizing the total operation time, in a cross-docking warehouse with one receiving, and one shipping dock is coded and solved through GAMS software on a computer with 2 GB RAM and 2.53 GHz central processor and optimal solutions obtained by the proposed model have been compared with the model presented by [7] in Table 2. Data in Table 2 show that in small and medium size of problem our model is more efficient. In addition, to solve the two-objective problem, nondominated storing genetic algorithm (NSGA-II) and nondominated ranking genetic algorithm (NRGA) have been used. Optimization of multiobjective is different from single-objective issues because it contains several goals that must pay attention simultaneously to all goals in optimization. In this paper, we use two nondominated storing genetic algorithm and nondominated ranking genetic algorithm for large size of problem.

4.1. *Controlled NSGA-II.*

Nondominated storing genetic algorithm is one of the most efficient and well-known multiobjective optimization algorithms presented by [32]. However, controlled NSGA-II presented by [33] is the same as NSGA-II, but here you use the concept of controlled elitism to create the next generation. The method of solving

Table 3: Numerical examples of different sizes.

Problem	Receiving truck	Shipping truck	Receiving dock	Shipping dock	Products types
1	10	13	6	5	5
2	16	15	11	8	6
3	20	17	15	8	11
4	20	28	16	9	19
5	23	30	18	10	25
6	25	31	19	14	27
7	36	35	19	17	31
8	47	41	23	17	33
9	48	43	23	21	35
10	97	88	25	25	40

the above model is based on the nondominated storing genetic algorithm according to Figure 3.

4.2. Nondominated Ranking Genetic Algorithm (NRGA). A new population-based multiobjective evolutionary algorithm called genetic algorithm based on nondominated ranking nondominatedhas been successfully developed by [34] to optimize non-convex, nonlinear, and discrete functions. They studied multiobjective algorithms that worked on nondominated sorting. They noticed three problems in these algorithms.

(i) The computational complexity was $O(mn2^m)$ (M: the number of targets and N: the population size)

(ii) Lack of efficient elitism

(iii) The need to specify parameters in the division process

Based on the problems in their previous approaches, they developed a new approach by combining the roulette wheeling algorithm based on ranking and the Pareto-based population ranking algorithm, which was named NRGA (nondominated ranking genetic algorithm). Their proposed algorithm solves the three problems in previous approaches. In this combination, a two-layer ranking based on the selection operator of roulette wheeling is offered, which randomly selects the new generation from the parent generation based on the selection of the best solutions (in terms of fit and extent). This algorithm is in most cases capable of achieving better scalability of the solutions at the Pareto boundary and the earlier convergence at the Pareto optimal boundary, compared with other multiobjective evolutionary algorithms. However, the difference between the NRGA and the controlled NSGA-II is in the strategy selection section and the population sorting and selection for the next generation.

4.3. Numerical Example. To illustrate the performance of the proposed strategy of the model, ten sets of problems were randomly generated, in medium and large size. Table 3 represents the size of the test problem sets. The number of product units unloaded from inbound trucks, or loaded onto outbound trucks, receiving and shipping trucks, and receiving and shipping docks are randomly generated from a uniform distribution over (5, 100). The data generated for

Table 4: Parameters for NSGA-II and NRGA.

NSGA-II				NRGA			
Parameters	1	2	3	Parameters	1	2	3
Pc	0.7	0.8	0.85	Pc	0.7	0.85	0.9
Pm	0.2	0.25	0.3	Pm	0.1	0.2	0.3
NPop	25	50	150	NPop	25	50	150
Max Gen	50	75	100	Max Gen	75	100	150

medium and large size instances follow the restriction of a cross-docking system in which the inbound flow should be equal to the outbound flow. Each example is run 10 times by NSGA-II and NRGA in MATLAB software (R2009a) on a computer with 2 GB RAM and 2.53 GHz central processor. For one of the examples, an experimental design is employed to quickly converge and more accurately answer for the parameters of the two proposed algorithms. The Taguchi method is used here to set parameters.

5. Taguchi Method

There are several statistical methods for designing experiments to adjust the parameters of the algorithms. Taguchi improved a family of matrices of partial factorial experiments, so that after many experiments, he could design experiments in a way that the number of experiments for one problem reduced. In the Taguchi method, orthogonal arrays are used to study a large number of decision variables with a small number of experiments. Taguchi divides the factors into two main classes: controllable factors and sound factors. Sound factors are those that cannot be controlled directly. When removing sound factors is impossible, the Taguchi method seeks to minimize the impact of the sounds and determine the optimal level of controllable factors. The purpose of this study was to find the parameters of NSGA-II and NRGA as receiving variables to obtain the optimal response (Y). To set the problem parameter with 10 receiving trucks, 13 shipping trucks, 6 receiving docks, 5 shipping docks, and 5 different product types are reviewed. The Taguchi method has been used to adjust parameters of population size (Npop), probability of crossover (Pc), probability of mutation (Pm), and reproduction (Max Gen) in NSGA-II and NRGA. The Taguchi method here is applied for four factors at three levels, so that the factors are the same parameters of the two algorithms and each factor is at three

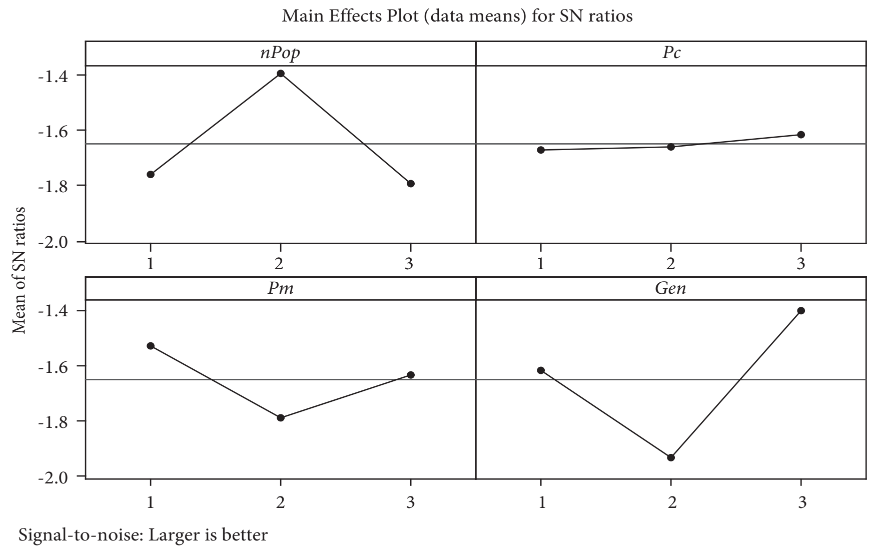

Figure 4: Values of different levels of parameters in S/N ratio for NSGA-II.

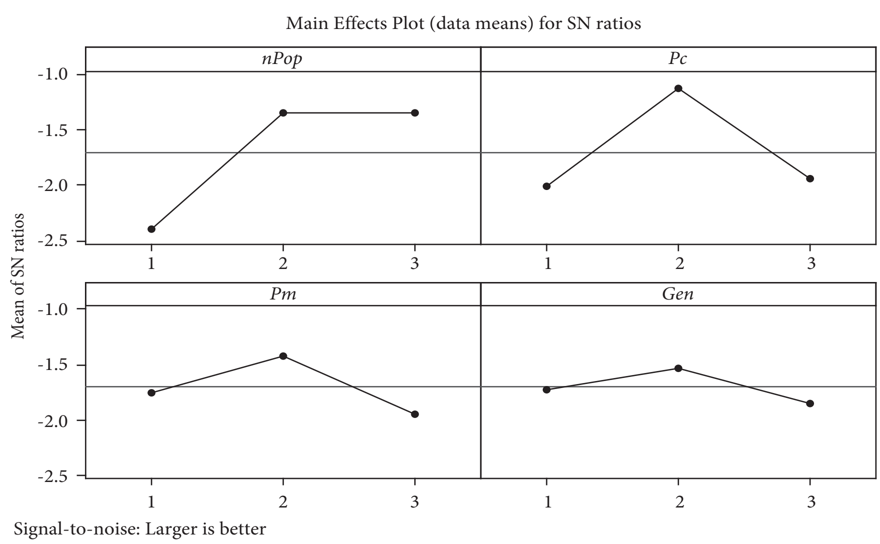

Figure 5: Values of different levels of parameters in the S/N ratio for NRGA.

Table 5: Best value of parameters for NSGA-II and NRGA.

NSGA-II		NRGA	
Parameter	Value	Parameter	Value
Pc	0.85	Pc	0.85
Pm	0.2	Pm	0.2
Gen	100	Gen	100
NPop	50	NPop	50

levels. Table 4 shows the values of the factors at each level for NSGA-II and NRGA so that the numbers 1, 2, and 3 are the levels of each factor. The numbers in Table 4 are based on the trial and error method and the researchers' suggestion.

Given the dual purpose of the model, the Taguchi parameters must be adjusted in the two-objective space. For this purpose, for the mentioned problem with 3 receiving trucks, 2 receiving docks, 4 shipping docks, 4 shipping trucks, and 6 different product types, at each level, the normalized weighted sum of the time algorithm performance criteria (CPU time), number of Pareto solutions (NOS), first objective function (completion time), second objective function (cost), and generational distance (GD) were calculated, so that the values obtained for each criterion from 10 times of the algorithm's execution, based on nature of the positive or negative criteria, are normalized using a method according to the SAW principles. According to this method, the sum of the weighted values of the criteria is calculated at each level and the maximum value is used as the main parameter to calculate S/N ratios (here, it is assumed that the weight of the criteria is equal to 0.2). Now, considering the calculated values after 10 run times for each case and the S/N ratios for the different parameters of the problem for NSGA-II and NRGA, the average graphs of parameters for S/N rates at different levels are shown in

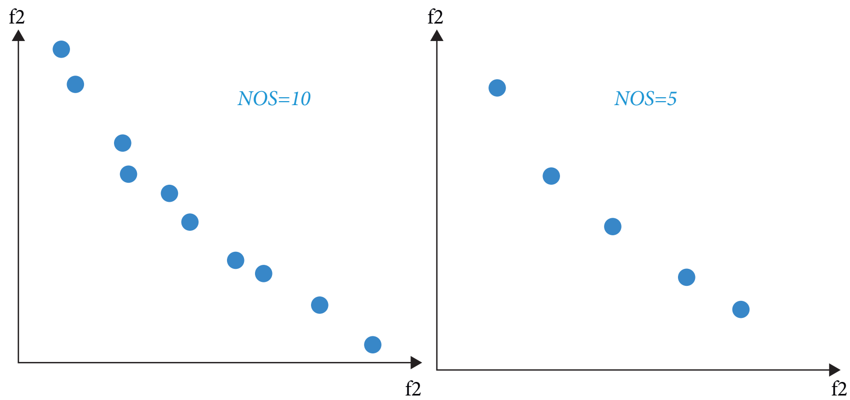

FIGURE 6: Method to calculate the number of Pareto solutions.

Figures 4 and 5. Given equation (1), the lower the S/N ratio, the better the answers of algorithm. According to Figure 5, the optimal values of appropriate parameters for NSGA-II and NRGA are in accordance with Table 5.

$$\frac{S}{N_S} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right). \quad (25)$$

6. Computational Result

In this section, five benchmarks are presented to evaluate multiobjective optimization algorithms:

6.1. Most Expansion. The below criterion measures the length of the spatial cube diameter applied by an ultimate measure of the objectives, for the set of nondominated solutions. Equation (26) illustrates the computational procedures of this index.

$$D = \sqrt{\sum_{J=1}^{M} \max_i f_i^j - \min_i f_i^j 2}. \quad (26)$$

6.2. Spacing. This following criterion calculates the relative distance of successive solutions using equations (27)–(29).

$$S = \sqrt{\frac{1}{|n|}\sum_{i=1}^{n}\left(d_{i-}\overline{d}\right)^2}, \quad (27)$$

$$d_i = \min \sum_{m=1}^{2} |f_m^i - f_m^k| \quad (28)$$

$$\overline{d} = \sum_{i}^{n} \frac{d_i}{|n|}. \quad (29)$$

The measured distance is equal to the lowest value of the sum of the absolute values of the difference in the values of the objective functions between the ith answer and the solutions in the final nondominated set. It is noteworthy that this distance criterion is different from the criterion of the lowest elucidation distance among the solutions.

6.3. Number of Pareto Solutions (NOSs). The NOS benchmark represents the number of optimal Pareto solutions that can be found in any algorithm. Figure 6 provides an example for calculating NOS.

6.4. Generational Distance (GD). This criterion finds the average distance of Q solutions from p^*, instead of finding answers from the set of nondominated Q solutions belonging or not to the optimal Pareto solutions.

TABLE 6: Comparative criteria value for NSGA-II algorithm.

Problem	$\overline{D}$	$\overline{S}$	$\overline{\text{NOS}}$	$\overline{\text{GD}}$	$\overline{T}$
1	0.4283	4110.72	3	18.132	37740
2	0.7345	2800.82	7	19.44	173656
3	0.6532	2619.86	24	18.61	5172159
4	0.9821	5445.06	17	24.23	587126
5	0.8763	5701.82	14	24.93	331846
6	0.4553	5367.43	18	26.06	1759341
7	0.9234	4112.76	18	19.01	1378814
8	0.8766	5723.18	23	22.13	3333969
9	0.8661	4598.12	20	27.43	19109557
10	0.9012	3892.74	24	23.19	59399282

TABLE 7: Comparative criteria value for NRGA.

Problem	$\overline{D}$	$\overline{S}$	$\overline{\text{NOS}}$	$\overline{\text{GD}}$	$\overline{T}$
1	0.7802	4554.22	12	17.66	174211
2	0.9871	3442.12	3	18.92	38861
3	0.8993	3032.11	32	16.23	5503859
4	0.9887	1790.21	20	21.63	481018
5	0.7864	3309.28	14	27.19	328979
6	0.7602	5466.09	22	25.22	1765051
7	0.9103	5990.66	23	24.93	1380413
8	0.8872	3354.88	28	32.11	3344819
9	0.7898	4909.31	35	19.87	19125443
10	0.9821	5891.01	32	17.14	59388502

Table 8: Values of RPD criteria for NSGA-II.

Problem	$\overline{T}$	$\overline{P}$	Best $\overline{T}$	Best $\overline{P}$	RPD $\overline{T}$	RPD $\overline{P}$
1	0.4283	3	0.4185	3	2.35	0
2	0.4982	7	0.4282	9	16.35	17.77
3	0.7226	14	0.4416	30	63.62	52.33
4	0.4946	18	0.4209	31	17.52	42.90
5	0.9645	18	0.9470	27	1.85	32.60
6	0.9080	19	0.4482	30	102.58	37
7	0.5622	24	0.4500	37	24.94	35.67
8	0.9301	24	0.4988	36	86.43	33.05
9	1.1138	20	0.9744	38	14.31	42.84
10	1.4798	24	1.3758	41	7.55	40.48

Table 9: Values of RPD criteria for NRGA.

Problem	$\overline{T}$	$\overline{P}$	Best $\overline{T}$	Best $\overline{P}$	RPD $\overline{T}$	RPD $\overline{P}$
1	0.5235	4	0.4170	6	25.54	38.33
2	0.5211	13	0.4017	19	29.71	32.63
3	0.5279	15	0.4074	28	40.25	45.92
4	0.5355	21	0.4209	33	27.23	36.96
5	1.0174	24	0.9306	38	9.32	37.90
6	0.9381	23	0.9104	39	30.3	41.53
7	0.8109	28	0.4398	40	84.38	29
8	0.7452	32	0.4447	39	65.57	17.94
9	1.0331	36	0.9926	40	4.07	11
10	1.5206	32	1.4012	44	8.51	27.27

$$\mathrm{GD} = \frac{\left(\sum_i^Q d_i^p\right)^{1/p}}{|Q|}. \quad (30)$$

For $p = 2$, the d_i parameter is equal to the Euclidean distance (in the target space) between the solutions of i belonging to q and the closest member of p^*.

$$d_i = \min_{k=1} \sqrt{\sum_{m=1}^{M} \left(f_m^{(i)} - f_m^{*\,(k)}\right)^2}. \quad (31)$$

6.5. Algorithm Run Time (CPU Time). Another standard criterion for comparing multiobjective algorithms is the use of the algorithm's runtime criterion, which is the lower this time, the better the algorithm's performance.

After defining standard benchmarks for comparing Pareto-based multiobjective algorithms in Tables 6 and 7, these criteria are calculated for each of the experimental production problems, and then, based on the results, algorithms are studied statistically and using analytical methods. Since comparing the performance of algorithms on the basis of the values of one of the criteria does not provide a clear solution, therefore, the combination and synthetic methods are used to compare the algorithms and select the most efficient algorithm. One of these methods is the percentage of relative deviation. To measure algorithms, residual prediction deviation (RPD) is used whose computing method is based on

$$\mathrm{RPD} = \frac{\mathrm{Alg}_{sol} - \mathrm{Best}_{sol}}{\mathrm{Best}_{sol}} 100. \quad (32)$$

In this equation, $\mathrm{Alg}_{\mathrm{sol}}$ is the value obtained for each problem by the algorithm. $\mathrm{Best}_{\mathrm{sol}}$ is the best value among the solved sample issues. The lowest the average values of RPD, the better solutions obtained from the algorithm. The above criterion is calculated for two factors, the running time of the program (T) and the number of Pareto solutions (P). Moreover, it was implemented ten times for ten different problems that in Tables 8 and 9, the average values for desired criteria for NSGA-II and NRGA.

As Tables 8 and 9 illustrate, it is not easy to decide accurately which one of the two algorithms is more efficient than the other in averages of the number of solutions RPD ($\overline{T}$) and runtime RPD ($\overline{P}$). Therefore, two methods were used to evaluate the results of the two algorithms. Applying SAW method is one of the multiple-criteria decision-making methods or using statistical methods, which used one-way statistical hypothesis testing for runtime and number of solution averages.

6.6. Investigation of Results Using Multicriteria Decision-Making (MADM). To decide different problems, there are a large number of models. In general, these models are divided into two main categories, multicriteria decision-making models (MADMs) and multiobjective decision-making models (MODMs). By adopting MADM method, the decision-maker must select one or more of a limited set of alternatives so that each alternative was evaluated by at least 2 criteria. The simple additive weighting method (SAW) is the most popular method of MADM methods. SAW method is defined as follows: assume that F is a decision matrix. First, a numerical scaling system, for example, normalization, is used to obtain the score for each alternative. A score in SAW method is the sum of the scores of all the criteria for each alternative in the decision matrix. In decision matrix F equation (34) A_r is alternative r, B_j is jth criterion, and X_{rj} is the value of alternative r for jth criterion. In general, the value of an alternative in SAW method is calculated as follows:

$$\mathbf{V}\left(\mathbf{A_r}\right) = \mathbf{V_r} = \overset{\mathbf{n}}{\underset{\mathrm{j=1}}{\text{å}}} \mathbf{W_j V_j}\left(\mathbf{X_{rj}}\right)\mathbf{r} = 1.2\ldots.\mathbf{L}. \quad (33)$$

Table 10: Superior performance of each problem based on SAW method for NSGA-II.

Problems	NSGA-II			
	CPU time (second)	Total cost	Makespan (second)	Pareto solution
1	0.440915	741	36055	3
2	0.431867	26531	175532	6
3	0.497491	41031	324173	29
4	0.431391	48770	573148	21
5	0.946947	87931	1406232	13
6	0.463434	103839	1756427	29
7	0.463434	185443	3287332	29
8	0.498891	140617	2181641	19
9	0.979835	1433406	19106634	13
10	1.50751	6382844	59333435	29
Average	0.6661608	845115.3	8818060.9	19.1

Table 11: Superior performance of each problem based on SAW method for NRGA.

Problems	NRGA			
	CPU time (second)	Total cost	Makespan (second)	Pareto solution
1	0.417008	741	36015	4
2	0.423161	26530	173208	15
3	0.427635	41032	323804	27
4	0.454585	131655	63312	33
5	0.979052	79483	1370871	10
6	0.914421	172774	1784343	9
7	0.952752	185856	3334967	33
8	0.523281	278420	5508685	35
9	0.992697	1592228	19135640	40
10	1.544602	7600860	59414621	44
Average	0.7629194	10110957.9	9114546.6	25

Table 12: Comparison of results for all issues.

	Average makespan (second)	Average total cost
NSGA-II	881806.09	84511.3
NRGA	9114546.6	1010957.9

In the above equation, L is the number of alternatives, n is the number of criteria, $V_j(x_{i,j})$ is the value of ith criterion under the jth alternative, and w_j is the weight of jth alterative.

$$F = \begin{array}{c} \\ A_1 \\ \vdots \\ A_l \end{array} \begin{array}{c} \begin{array}{ccc} B_1 & \cdots & B_n \end{array} \\ \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{l1} & \cdots & x_{ln} \end{bmatrix} \end{array}. \quad (34)$$

In this study, NSGA-II and NRGA, alternatives (choices), makespan, and total cost are also criteria. Here, the criteria were weighted after normalization (the criteria weight is considered to be 0.5) and the best execution of each problem is selected by SAW method. Tables 10 and 11 show the results for NSGA-II and NRGA.

The results of Table 12 show that, in general, considering two criteria makespan and total cost, NSGA-II is more efficient than NRGA from SAW perspective.

6.7. Result Analysis Using Statistical Method. To compare the results of NSGA-II and NRGA retained in this method, a statistical method was applied. Here, two one-way assumption tests for values of RPD(P) and RPD(T) for NRGA and NSGA-II were considered. In this example, the confidence coefficient is equal to 0.95. It means $(1-\alpha=0.95)$.

Equations (35)–(38) show one-way statistical tests for $RPD\,(\overline{P})$ and $RPD\,(\overline{T})$ and values of t-distribution for $RPD\,(\overline{P})$ and $RPD\,(\overline{T})$, respectively, so that $\overline{T}$ is defined as the runtime average and $\overline{P}$ is equal to the average of the number of solutions. This test is performed assuming that variances are known.

$$\begin{aligned} H_0&: \mu_{\overline{T}_{\text{NRGA}}} \ge \mu_{\overline{T}_{\text{NSGA}}}, \\ H_1&: \mu_{\overline{T}_{\text{NRGA}}} < \mu_{\overline{T}_{\text{NSGA}}}, \end{aligned} \quad (35)$$

$$\begin{aligned} H_0&: \mu_{\overline{P}_{\text{NRGA}}} \ge \mu_{\overline{P}_{\text{NSGA}}}, \\ H_1&: \mu_{\overline{P}_{\text{NRGA}}} < \mu_{\overline{P}_{\text{NSGA}}}, \end{aligned} \quad (36)$$

$$t_{\text{Distribution}} = \frac{\overline{T}_{\text{NRGA}} - \overline{T}_{\text{NSGA}}}{S_p^2\sqrt{1/n_{\text{NRGA}} + 1/n_{\text{NSGA}}}}, \quad (37)$$

$$t_{\text{Distribution}} = \frac{\overline{P}_{\text{NRGA}} - \overline{P}_{\text{NSGA}}}{S_p^2\sqrt{1/n_{\text{NRGA}} + 1/n_{\text{NSGA}}}}. \quad (38)$$

In the above equation, S_p^2 is defined as follows in which S_{NRGA}^2 and S_{NSGA}^2 are equal to sample variance for NSGA-II and NRGA. If $t_{distribution} > t_{1-\propto}$, thus, H_0 is rejected and H_1 is accepted; otherwise, H_1 is rejected and H_0 is accepted.

$$S_p^2 = \frac{(n_{\text{NRGA}} - 1)S_{\text{NRGA}}^2 + (n_{\text{NSGA}} - 1)S_{\text{NSGA}}^2}{n_{\text{NRGA}} + n_{\text{NSGA}} - 2}. \quad (39)$$

The results of RPD $(\overline{P})$ values for ten examples made here, after solving by presented algorithms, are given in Tables 11 and 12. The calculation is as follows:

$$\begin{aligned} t_{\text{Distribution}} &= \frac{29.96 - 33.74}{1050.47\sqrt{1/10 + 1/10}} = -0.008, \\ t_{0.95,18} &= 1.73. \end{aligned} \quad (40)$$

According to the above calculations, $t_{\text{distribution}} > t_{0.95,18}$ is not established; thus, H_1 assumption is rejected and H_0 is accepted. Therefore, given the lower the average number of solutions, the better, then, NSGA-II is better than NRGA regarding RPD $(\overline{P})$ criterion. The study of results with statistical method showed that NSGA-II is better than NRGA in terms of two criteria RPD $(\overline{P})$ and RPD $(\overline{T})$. The results of RPD $(\overline{T})$ values for ten examples made here, after solving by presented algorithms, are given in Tables 8 and 9. The calculation is as follows:

$$\begin{aligned} t_{\text{Distribution}} &= \frac{31.84 - 33.86}{172.78\sqrt{1/10 + 1/10}} = -0.026, \\ t_{0.95,18} &= 1.73. \end{aligned} \quad (41)$$

According to the above calculations, $t_{\text{distribution}} > t_{0.95,18}$ is not established; thus, H_1 assumption is rejected and H_0 is accepted. Therefore, given the lower the average runtime, the better, then, NSGA-II is better than NRGA regarding RPD $(\overline{T})$ criterion. The study of results with statistical method showed that NSGA-II is better than NRGA in terms of two criteria RPD $(\overline{P})$ and RPD $(\overline{T})$.

6.8. Managerial Insights and Practical Implications. The results of this study can be useful for organizations such as municipalities, transportation organizations, and organizations that are somehow related to traffic. One of the advantages of the presented methods is that NSGA-II and NRGA use only the values of the objective function to perform the optimization process and do not require additional information such as the function derivative. Also, the disadvantages of the proposed methods are that the final solution in NSGA-II and NRGA depends on the coder's skill in defining chromosomes and the initial value of its parameters.

7. Conclusion and Future Research

In this study, the problem of scheduling trucks in a cross-docking system, to minimize time of the whole process and cost of handling inside the terminal, has been investigated. To be more realistic, the cross-docking problem was considered with multiple receiving and shipping docks. Also, we assumed that there is a temporary storage facility near the shipping docks with limited capacity. The developed model was solved by GAMS software, and the obtained solutions were compared with the model presented in [7]. The results showed that in solving small size of problem, the proposed model in this study is more efficient and we found better solutions for objective function (makespan).

Due to the complexity of multiobjective mathematical model, two different metaheuristic algorithms (NSGA-II and NRGA) were applied to solve the medium and large size of problem. Due to getting better result, the proposed algorithms were tuned by applying the Taguchi method. To decide which algorithms are more effective, two methods were used to compare the results of the two algorithms: the two metaheuristic algorithms (NSGA-II and NRGA) were compared based on 4 criteria (CPU time, total cost, makespan, and number of Pareto solution) by means of SAW method, which is one of the multicriteria decision-making methods. The statistical hypothesis testing (t-test) is used for determining the best algorithm based on the average runtime and average number of Pareto solutions. Finally, both methods showed that NSGA-II metaheuristic algorithm was more effective than NRGA metaheuristic algorithm and provided better solutions. As there was no official database for some parts of cost elements, the driver's estimations were asked to help. The questions about the shipping costs for each route have been categorized, and the estimated costs have been entered into the mathematical model.

The future research suggestions of this paper can be divided into two parts:

(i) Development of methods such as Tabu search algorithm, ant colony optimization, and particle swarm optimization for the problem and comparison with the proposed methods

(ii) Exploring the feasibility of utilizing intelligent combination systems and hybrid heuristic methods for model development

(iii) Using other methods, for tuning problem parameters

(iv) Changes in the structure of the problem

In the model presented in this paper, the dock holding pattern was considered static, so one of the topics for future research could be different dock holding patterns. In this research, it is assumed that trucks are available at the start time of scheduling, so considering uncertainty in the arrival time of receiving trucks is suggested. Clearly, considering this assumption adds complexity to the problem.

Data Availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Integrated Design of Cellular Production System Using Branch and Bound Algorithm

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Most research done on the design of cellular production systems also has examined one of the main areas of design including cell formation, cellular layout, and material handling. Some research studies also have been done by considering the lack of independence of these areas, two areas simultaneously, and three areas sequentially. The main goal of this research is to present a mathematical framework for designing and also providing the efficient methods for solving the desired problem. Therefore, the main contribution of this paper is to determine the same component according to the characteristics of designs and production requirements. For this purpose, an overall design of a cellular production system or material handling system with cellular layout is examined. Then, the mathematical formulation is presented for the problem and then an efficient solution is presented for the problem. In the provided model, the interaction effects between designs fields are provided. A branch and bound algorithm is also provided to solve this problem. The performance of the provided algorithm and the performance of the provided approach are investigated by using different numerical samples. The results show the performance of the provided algorithm and approach in the design of cellular production systems.

1. Introduction

The issue of cell production integration design is one of the most important and complex issues in the field of production management; because of the existence of a program that can provide an optimal or near-optimal answer in the face of unexpected events or planned stops, it is considered a good program. Today, manufacturing organizations are mostly focused on increasing productivity. To achieve this, it is necessary to have a regular schedule that takes into account the production schedule and maintenance schedule at the same time. In previous research, each of the dual production and maintenance plans has been examined separately. However, there may be limitations such as limited access to productive resources that occur due to a lack of attention to regular operations. For this purpose, by following a regular procedure, we explain simultaneous integration planning for production and maintenance planning, in order to reduce production costs and increase the reliability of production systems [1].

In most production units, effective information is at an undesirable level of coordination and exchange with other activities. The result of such activities is nothing but a waste of resources (cost, time, materials, etc.) [2]. It is very clear that all parts of the production unit are interdependent and it is necessary to use an integrated format that makes vital factors to make management decisions [1]. The need for integration has long been considered by researchers and industry managers. Therefore, in integrated cellular production, it can be seen that the integration of vital information of different parts of production has been the focus of many researchers, because in the past few decades, there have always been many concerns regarding the integration of different areas related to production activities. Areas that are the beating heart of production units should be used in various decisions. Due to the interaction of each of these areas, they cannot be considered as islands and it is very appropriate and reasonable to plan a mechanism that can bring all the important factors together as much as possible Dymitrowski and Mielcarek [3].

Recent advances in the integration of preventive production and maintenance have included linking the issues of economic production value, preventive maintenance policies, and simultaneous production control of preventive maintenance rates [4]. On the other hand, research that has focused on the integration of production, maintenance, and repairs dates back to the 1970s and 1980s. Research in this period focused on several critical effects, such as the effect of production complexity and technology, speed of operation, commissioning planning, and design of tolerances considering the deterioration of production devices and the impact of repair inspection scheduling on production flow and some research has focused on integrating production and maintenance into system depreciation [5].

According to the above-mentioned, designing an efficient cellular production system involves many different decisions. The most important issue in cellular production systems includes cell formation (CF), cellular layout (CL), and management of material handling (MH). Cell formation includes grouping the similar parts as the families of parts and grouping machines into cells. For this purpose, we can determine the same component according to the characteristics of designs and production requirements. Cellular layout has two aspects: cellular layout in the workshop and machinery layout within cells. Design of material handling systems includes determining the movement type within cells and design of delivery locations and receiving the production cells. Therefore, the main contribution of the paper is as follows:

(i) Presenting a mathematical framework for designing and also providing the efficient methods for solving the desired problem.

(ii) Determining the same component according to the characteristics of designs and production requirements.

The rest of paper is organized as follows: Section 2 presents a literature review. In Section 3, presents the proposed framework. In Section 4, results, validation, and sensitivity analysis are presented. In Section 4, managerial insight is presented and finally in Section 6, overall conclusion and suggestion for future research are presented.

2. Literature Review

In most studies, cell formation is considered as default or intercellular and within cellular problems which are examined independently. Salum [6] provided two-step procedures for solving the cellular layout through simulation. Sarker and Xu [7] provided a method according to the sequencing problems for solving the formation cell problem and intracellular layout by minimizing the total costs of material flow and investments for machine preparing. Bazargan-Lari et al. [8] has provided a multi-objective mathematical model to determine the machine layout and cells in the cellular production environment. The provided model considers quantitative and quantitative aspects. The more complete form of the above model was provided by Bazargan-Lari et al. [8] that simultaneously considers the machine grouping and part grouping, and intercellular layout. The provided solution is simulated by a combination of simulated annealing methods and a fuzzy goal programming. And for a number of different cells, this algorithm provides different layouts to decision-makers. Intercellular layout problem has been studied by Solimanpur et al. This problem is modeled as a quadratic assignment problem (QAP) and Ant algorithm is used to solve it. Yu and Sarker [9] considered machine cell-location as a one-dimension problem and in situations that the distance between cells is not equal. Chan et al. [10] provided a two-stage approach for solving the cell formation and intracellular layout problems. The first step includes determining the family segments and machine cell packaging. In the second phase, the cell formation problem is investigated by considering the sequence machine. Rokhi Nasab et al. [11] addressed business intelligence as a process in which raw data is converted into business and management information using data mining. They focused on e-business and data mining and outlined the challenges and benefits of business data mining. They also presented a classification of data mining applications used in e-business. Abnusian et al. [12] reviewed data mining applications in e-commerce, presented its pros and cons, proposed solutions to control its challenges, and highlighted its benefits. Accordingly, data mining is able to improve e-commerce and increase the profitability and customer satisfaction. Nowruzi and Jafari [13] pointed out that one of the most important steps of business process management lifecycle is to monitor the proper implementation of modeled processes in the organization. Questions raised in order to monitor and decide on the improvement of business processes are sometimes complex questions about the efficiency, accuracy of implementation, the way the processes are actually implemented, and social networks formed in the organization. In addition to answering these questions, there are complex patterns and rules that need to be discovered and extracted from data to support the decision-making of a team of process excellence to improve organizational processes. In other words, process mining is a technique that in addition to answering common questions in this regard by exploring patterns, processes, and rules can be used as a decision support system in the business excellence center of the organization. Jia et al. [14] in a study presented the ant colony optimization algorithm for scheduling jobs with fuzzy processing time on parallel batch machines with different capacities. Jobs have non-uniform sizes and fuzzy processing time. After constructing a mathematical model of this problem, in this paper a fuzzy ant colony optimization (FACO) algorithm is proposed. Based on the capacity limit of the device, two lists of candidates are used to select a job to build the batch. In addition, based on the empty space of the solution, heuristic information is designed for each candidate list to guide the ant. Also, fuzzy local optimization algorithm is included to improve solution quality. Finally, the proposed algorithm is compared with several more advanced algorithms than simulated experiments and statistical tests. Comparative results show that the proposed algorithm can find better solutions in a reasonable time than other comparative algorithms. Minatogawa et al. [15] argued that business model innovation is the organizational key to achieving sustainability. However, there are many problems associated with business model innovation. They used a scientific design method to create an artifact to assist in business model innovation measures. The artifact uses performance metrics to measure a company's business model, which uses big data analysis to innovate a customer-centric business model. Then, the artifact was used in a case study, whose findings show that it successfully contributes to an active and continuous effort to innovate the business model. Although the artifact is technically accessible in the context of small businesses, it helps democratize business model innovation practices and big data analytics across large organizations. Martins et al. [1] aimed to evaluate the perception of experts on the contribution of the Brazilian industrial sector in terms of sustainable development, focusing in particular on three of the 17 Sustainable Development Goals (SDG) presented by United Nations (UN). For this purpose, a survey was conducted with professionals from Brazilian industry in order to identify their perceptions. It obtained sixty-one answers and the collected data was evaluated technically and descriptively by TOPSIS analysis. Dymitrowski and Mielcarek [3] determined the influence of BMI based on new technologies on a company's competitive advantage. In order to accomplish the aim, a quantitative research was performed using the computer assisted telephone interview (CATI) method. There are two main outcomes of the research. Firstly, BMI based on new technologies has a positive influence on a company's competitive advantage. Secondly, it was proven that the greater the use of technologies for BMI, the greater a company's competitive advantage is. Franco et al. [2] built a tool for dynamic capabilities evaluation through a systematic literature review. Then the tool was evaluated based on a three-year, in-depth case study of a software company. Findings show that the current business model has a central role in shaping dynamic capabilities for business model innovation. The proposed measures encompass activities and practices and business model structure, highlighting the relevance of the co-evolution between business model and dynamic capabilities. In [16], according to the scientific literature clustering paradigm of grounded theory is used to design business model innovation theory model (BMITM). BMITM and the business model innovation options traced back from 870 labels in the grounded process are integrated into a unified framework to build the business model innovation canvas (BMIC). Luo et al.'s [5] study aimed to conceptualize the business model innovation BMI themes by integrating the business model theory with institutional attributes of BMI. Based on the research literature, two themes of pioneering and perfection were proposed in BMI, where pioneering BMI creates new market rules and perfect BMI improves existing trading rules. After conducting the studies, two-item scales were developed and empirically validated using two primary data sets collected separately in China. The results suggest that both transactional innovation and legitimacy building are critical to BMI in the emerging market. Dai and Liang [17]. Taking the dynamic capability theory as the research framework, using a two-stage questionnaire survey and 318 Chinese enterprises as samples, this study investigates the impact mechanism of big data technical skills on novel business model innovation, as well as the mediator of resource integration and the moderator of environmental uncertainty. The hierarchical regression results show the following: (1) big data technical skills have a significant positive impact on novel business model innovation; (2) resource integration is a partial mediator between big data technical skills and novel business model innovation; (3) environmental uncertainty regulates the relationship between big data technical skills and resource integration; that is, the higher the environmental uncertainty, the stronger the positive relationship between big data technical skills and resource integration; (4) environmental uncertainty has no significant moderating effect on the mediating role of resource integration between big data technology skills and novel business model innovation.

2.1. Research Gap. According to the above-mentioned, this paper investigates the design of cellular production systems and material handling systems with cellular layout. For this purpose, a suitable mathematical model is provided to solve this problem and then an efficient solution for designing is proposed. In the proposed model, interaction effect of different areas will be considered. The effectiveness of the proposed approach is investigated with respect to the various indices. For this purpose, appropriate performance indices are defined and used for cellular production systems. So, the main purpose of this study is providing a mathematical framework for designing and also providing efficient methods for solving the desired problem. The problems of cell formation and cellular layout have a relation with each other and the obtained answer of these problems influences the other answer. If the problem of cell formation is solved regardless of cellular layout, since the intercellular movement and cell spacing are linked to each other, the obtained answer will not be an accurate answer. On the other hand, in order to solve the problem of cellular layout, the formation style of cells should be considered. In fact, the flow between cells and cell dimensions should be obtained from the formation cell problem. In many real situations, intercellular locating from the delivery point to another cell reception takes place. In such circumstances, the displacement between two cells is calculated according to the receipt and delivery points and distance between two cars should not be considered. In order to determine the cells delivery and receipt location, the material handling systems should be designed in cells. Another problem that should be considered is that by

Table 1: Categorized literature.

Author	Year	Model	Research method	Other factors	Tool
Mitogawa et al.	2020	BMI	Big data analysis	Sustainability	—
Martins et al.	2020	BMI	Questionnaire analysis	Sustainable development	TOPSIS
Mytrowsk and Mielcark	2021	BMI	Quantitative research	—	Questionnaire
Jin et al.	2021	BMI	Quantitative research	—	Grounded theory
Lou et al.	2022	BMI	—	—	—
Dai and Liang	2022	BMI	Big data analysis	Dynamic	Questionnaire
This research	2022	Cellular production systems	Big data analysis	Cellular layout	Branch and bound algorithm

considering the distance between receipt and delivery locations the problems of cell formation and intercellular layout are separated from intracellular layouts. In such situations, we can consider the problems of cell formation, intercellular layout, and designing the handling systems as an integrated issue and we can solve the intracellular layout, separately. In Table 1, we categorize literature-based goals, research method, and tools.

3. Research Method

3.1. Problem Statement. The model developed in this section considers the cell formation, intercellular layout, and design of the material handling systems. The final goal of this model is to determine the cell formation, cell layout in the workshop, and material flow in manufacturing systems. So the switching costs of intercellular components will minimize.

3.2. Problem Assumption. This model assumes the following:

(i) Intercellular layout is as a linear and unidirectional current.

(ii) In each cell, the receipt place is located in one side and delivery place is located in the other side.

(iii) Machines are in a shape of square and so the squares with unit dimensions are considered.

(iv) Space between machines is not considered, since the intercellular arrangement is linear and cells are rectangular.

(v) Each cell's width is one and its length equals the assigned machines.

(vi) The material flow in the cells is determined by the model. And this issue specified the receipt and delivery place of cells. For example, if the material flows in one cell are from left to right, the receipt location is in the left side of cell and its delivery place is located in the right side.

As mentioned, the current objective function is considered to minimize the intercellular material current. So, at first the current between machines is calculated according to the sequence operations and manufacturing volume by using the following formula:

$$f_{ij} = \sum_{k=1}^{n} P_k z_{ijk}. \quad (1)$$

In the previous equation, f_{ij} is the material current from machine I to machine j and P_k is the manufacturing volume and n is the total parts number. If in the sequence operations, part k of machine j is placed after the machine I, z_{ijk} is equal to 1 and otherwise it equals 0. The material current matrix from-to machine is determined by using the f_{ij} values.

3.3. Notation. In this section, all notations used in the model are described.

3.3.1. Indices. The used indices in this model are as follows:

M: the number of machines

C: the number of cells

R: maximum allowed machine in cells

V: the workshop length

3.3.2. Binary Variables

z_{ik}: if machine I is located to machine k, it equals 1 and otherwise 0

x_{ij}: if the machines I and j are located in one cell, it equals 1 and otherwise 0

s_k: if the material flow in cell k is from left to right, it equals 1 and otherwise 0

3.3.3. Integer Variables

l_k: the horizontal feature of cell's left side k

y_k: the vertical feature of cell k

3.3.4. Parameters

r_k: the horizontal feature of the right side of cell k

p_k: the horizontal feature of left side of cell

d_k: the horizontal of receipt place in cell k

3.4. Formulation. According to the introduce notation, the mathematical model is follows:

$$\min \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}\left(\left|\sum_{k=1}^{C} z_{ik}y_k - \sum_{k=1}^{C} z_{jk}y_k\right| + \left(1-x_{ij}\right)\left|\sum_{k=1}^{C} z_{ik}p_k - \sum_{k=1}^{C} z_{jk}p_k\right|\right), \quad (2)$$

$$\sum_{k=1}^{C} z_{ik} = 1, \quad i = 1,\ldots,m, \quad (3)$$

$$1 \le \sum_{i=1}^{m} z_{ik} \le R, \quad k = 1,\ldots,C, \quad (4)$$

$$x_{ij} = \sum_{k=1}^{C} z_{ik}z_{jk}, \quad \forall i, j, \quad (5)$$

$$r_k = l_k + \sum_{i=1}^{m} z_{ik}, \quad k = 1,\ldots,C, \quad (6)$$

$$p_k = l_k\left(1-s_k\right) + r_k s_k, \quad k = 1,\ldots,C, \quad (7)$$

$$d_k = l_k s_k + r_r\left(1-s_k\right), \quad k = 1,\ldots,C, \quad (8)$$

$$l_k - r_{k'} + Mu_{kk'} + Mv_{kk'} \ge 0, \quad \forall k,k',\ k \ne k', \quad (9)$$

$$l_{k'} - r_k + M\left(1-u_{kk'}\right) + Mv_{kk'} \ge 0, \quad \forall k,k',\ k \ne k', \quad (10)$$

$$y_k - y_{k'} + Mu_{kk'} + M\left(1-v_{kk'}\right) \ge 1, \quad \forall k,k',\ k \ne k', \quad (11)$$

$$y_{k'} - y_k + M\left(1-u_{kk'}\right) + M\left(1-v_{kk'}\right) \ge 1, \quad \forall k,k',\ k \ne k', \quad (12)$$

$$r_k \le H, \quad k = 1,2,\ldots,C, \quad (13)$$

$$y_k \le V, \quad k = 1,2,\ldots,C, \quad (14)$$

$$z_{ik}, s_k, u_{kk'}, v_{kk'} = 0 \text{ or} 1, \quad (15)$$

$$l_k, y_k = \text{integer}. \quad (16)$$

Equation (2) provides the objective function and it is defined as the total intracellular total current minimizing. The distance between two cells is calculated by the bridges distance of delivery place of a cell to the receipt place of another cell. Constraints (3) cause this situation that each machine is allocated to one cell and equation (4) shows the cell capacity constraints. Equation (5) makes this situation that if machines I and j are allocated to one cell, x_{ij} equals one and otherwise it takes the 0 value. Equation (6) states that the left side horizontal component equals the horizontal left component of a cell and the number of allocated machines to a cell. Constraints (7) and (8) determine the receipt and delivery locations of cell according to the cells currents. Constraints (9) and (10) guarantee the non-overlapping cells. Equations (11) and (12) specify the workshop level and equations (13) and (14) determine the type of variables. The linearization type of mathematical model of an integrated cell formation, intercellular layouts, and the material handling system design is described as follows.

The proposed objective function of model and constraints (5), (7), and (8) are nonlinear. The objective function is replaced by the following linear equation:

$$\min \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}\left(g_{ij} + h_{ij}\right). \quad (17)$$

And the following constraints are added to the model:

$$y_{ik}' \le y_{ik} + M\left(1-z_{ik}\right), \quad \forall i,k, \quad (18)$$

$$y_{ik}' \ge y_{ik} - M\left(1-z_{ik}\right), \quad \forall i,k, \quad (19)$$

$$y_{ik}' \le Mz_{ik}, \quad \forall i,k, \quad (20)$$

$$p_{ik}' \ge p_{ik} - M\left(1-z_{ik}\right), \quad \forall i,k, \quad (21)$$

$$p_{ik}' \le Mz_{ik}, \quad \forall i,k, \quad (22)$$

$$d_{ik}' \le d_{ik} + M\left(1-z_{ik}\right), \quad \forall i,k, \quad (23)$$

$$d_{ik}' \ge d_{ik} - M\left(1-z_{ik}\right), \quad \forall i,k, \quad (24)$$

$$d_{ik}' \le Mz_{ik}, \quad \forall i,k, \quad (25)$$

$$g_{ij} \ge \sum_{k=1}^{C} y_{ik}' - \sum_{k=1}^{C} y_{jk}', \quad \forall i, j, \quad (26)$$

$$g_{ij} \ge \sum_{k=1}^{C} y_{jk}' - \sum_{k=1}^{C} y_{ik}', \quad \forall i, j, \quad (27)$$

$$h_{ij} \ge \sum_{k=1}^{C} d_{ik}' - \sum_{k=1}^{C} p_{jk}' - Mx_{ij}, \quad \forall i, j, \quad (28)$$

$$h_{ij} \ge \sum_{k=1}^{C} p_{ik}' - \sum_{k=1}^{C} d_{jk}' - Mx_{ij}, \quad \forall i, j, \quad (29)$$

where y_{ik}', p_{ik}', d_{ik}', and d_{ik} are the variables that are replaced with the variables y_{ik}, p_{ik} in z_{ik}. Constraints (17)–(25) cause that these variables assign desired values. The constraints (26)–(29) are added to the objective function to eliminate absolute terms. In constraints (28) and (29), if the value of x_{ij} equals zero the amount of h_{ij} will equal to the second absolute term and otherwise, both constraints are imposed and since the objective function of the problem is as a type of minimizing, h_{ij} equals zero. Nonlinear equation (5) is replaced by the following equations:

$$Mx_{ijk}' \ge z_{ik} + z_{jk} - 1, \quad \forall i, j, k, \quad (30)$$

$$M\left(x_{ijk}' - 1\right) \le z_{ik} + z_{jk} - 2, \quad \forall i, j, k, \quad (31)$$

$$x_{ij} = \sum_{k=1}^{C} x_{ijk}', \quad \forall i, j. \tag{32}$$

In the previous equations, x_{ijk}' is a variable that if machines I and j are placed in cell k, equals one and otherwise it equals zero. Equation (32) causes that if there is a cell, machines I and j are allocated to it and in this situation, x_{ij} equals one and otherwise it equals zero. Finally, the linear constraints are replaced in (7) and (8) equations in the model.

$$\begin{aligned} p_k &\le l_k + Ms_k, \quad k = 1, \ldots, C, \\ p_k &\ge l_k - Ms_k, \quad k = 1, \ldots, C, \\ p_k &\le r_k + M(1 - s_k), \quad k = 1, \ldots, C, \\ p_k &\ge r_k - M(1 - s_k), \quad k = 1, \ldots, C, \\ d_k &\le l_k + M(1 - s_k), \quad k = 1, \ldots, C, \\ d_k &\ge l_k - M(1 - s_k), \quad k = 1, \ldots, C, \\ d_k &\le r_k + Ms_k, \quad k = 1, \ldots, C, \\ d_k &\ge r_k - Ms_k, \quad k = 1, \ldots, C. \end{aligned} \tag{33}$$

As noted above, if the problems of cell formation and intercellular layout are solved by considering the receipt and delivery places, the intercellular layout problem will be separate from cell formation and intercellular layout. In this section, we consider the intracellular layout by considering the linear machine layout. Because the material handling system is considered to be one-sided, the main purpose of this problem is minimizing the reversed current volume. The objective function is defined as to minimizing the amount of return flow. The goal of this study is finding a machine sequence that their return flow is minimized with respect to the matrix material flow. In order to design an efficient mathematical model, also a single zero variable and x_{ij} are used in this model. If the machine I is located before machine j, this variable has the 1 value and otherwise it takes zero. The mathematical model is as follows:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}\left(1 - x_{ij}\right), \tag{34}$$

$$x_{ij} = 1 - x_{ji}, \quad \forall i, \forall j, \ i \ne j, \tag{35}$$

$$x_{ij} \ge x_{ik} + x_{kj} - 1, \quad \forall i, \forall j, \forall k, \ i \ne j \ne k, \tag{36}$$

$$x_{ij} = 0 \text{ or} 1. \tag{37}$$

Equation (34) shows the objective function of the problem. Constraint (35) states that if the machine I is located before machine j, then the machine j cannot be located before machine i. Equation (36) states that if machine I is located after machine k and machine k is located after machine j, then the machine I will be located before machine j. Equation (37) shows that the variable used in the model is in the type of zero and one.

3.5. Solution Approach

3.5.1. The Integrated Problem Solving of Cell Formation, Intracellular Layout, and Material Handling System with Genetic Algorithm. Due to the complexity of the integrated cell problem, the intracellular arrangement, and the material handling system, the exact solution of the problem is only possible for small or medium-sized problems, and this section describes the problem solving with GA. The overall structure of algorithm and operators design will be explained. And in the next sections, some numerical examples are solved by the desired algorithm and the results will be analyzed.

3.5.2. Solving the Intracellular Layout Problem Using Proposed Branch and Bound Algorithm. The model which is provided to solve the intracellular problem is pure binary programming, and there are several ways to solve this problem. One of the common methods is the branch and bound algorithm. Of the in-layout problem, we consider m machine in one cell; in the provided model, the model's variables will be m^2 and the number of constraints is also obtained from the following equation:

$$N = m(m-1) + m(m-1)(m-2) = m(m-1)^2. \tag{38}$$

By considering the increase of problem dimensions, the number of variables and constraints will not increase exponentially and solving the desired problem will be possible with high dimensions. A problem with 30 machines can be solved with the proposed model by using the branch and bound algorithm and Lingo software. Furthermore, in designing the cellular production systems, even 10 machines within a cell counts as a large number and therefore in practical applications, using the desired model and solving it by using Lingo software can guarantee finding the optimal solutions in a very short time.

4. Results

First, investigating the performance of proposed approach is done. For this purpose, to evaluate the performance of proposed approach, a numerical example was used by Mahdavi et al. [18]. The reason for choosing this example is that in the approach of Mahdavi et al. [18] current matrix is used. The desired example has 25 machines and 40 components. The machine-component matrix of this example shows the operations sequence which is shown in Table 2. In order to compare this example with the obtained results by Mahdavi et al., the production volume is considered. As the production volume is the same, without prejudice of the generality, the production size is considered as Table 2.

4.1. Validation. In order to evaluate the effectiveness of the algorithm, 8 numerical samples with different aspects are considered; in order to produce the numerical samples in Table 3, the flow material matrix for each problem is randomly generated. Each of the samples is solved ten times and in each case the best answer, the mean, and median duration

Table 2: Machine-component matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1				5			3			1						4		2				6			
2	2	3															4								1
3			2								3									1					
4												1											2		
5				3								2						1							
6												3				2							1		
7				3			2			5						4		1							
8					1											3			2						
9			3								4									1					2
10								2	1																3
11								2					3								1				
12	1		4														3							2	5
13			3								2									1					
14			4		1						2									3					
15		4			3					5						1			2						
16				1			3									2		4							
17							1			3								2							
18														3	2							1			
19								1	3	2															
20																2							1		
21								1	3	2															
22			3					4	2								1								
23					2											3			1						
24					1											2									
25						1									3						2				
26				2								3			4								1		
27												1									3	2			
28								2	1	3															
29					3	2															1				
30				4			2									3		1							
31					2												1		3						
32													2	1	3							4			
33											1									3					2
34												2											1	3	
35						2									4						1	3			
36	2	3									4						1								
37							3					2											1		
38								2	3													1			
39							2					1													
40						2									3						1				

time are recorded. Then, according to the response of the branch and border and the genetic algorithm, the absolute relative error (ARE) was calculated as recommended by Abolghasemian et al. [19]. ARE is calculated as equation (39) based on the comparison of genetic output and branches and borders. Table 4 compares the results obtained from the branch and bound algorithm.

$$\frac{|\text{Branch and bound output} - \text{genetic algorithm output}|}{\text{genetic algorithm output}}. \tag{39}$$

According to the ARE results that shown in Table 4, for each sample, calculate lower than 0.1; therefore, the error difference between the results of the two algorithms is negligible.

4.2. Sensitivity Analysis. In this section, according to the examples considered in the previous step, we change the value of some key parameters to examine their effect on the target function according to the branch and boundary method. As shown in Figure 1, Experiment 4 significantly increases response time. The response time increases to the maximum possible in the sixth experiment. Given that there are many changes in the number of machines from Experiment 4, we can conclude that the response time is highly dependent on the number of machines.

4.3. Discussion. Integrated design like as mathematical modelling has already strongly transformed many industries such as cellular manufactures. The aim of this research is to study the impact and significance of integrated design in the cellular manufactures. For this purpose, we conducted a literature review of the research articles. As a result of these steps, research gaps in the application of integrated design were identified. These gaps can be beneficial for researchers

Table 3: Material flow matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	1	0	0	0
5	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	2	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
9	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
11	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
12	0	0	0	1	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
16	0	0	0	2	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
17	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0	0	0	0	0	3	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0
23	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
25	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Table 4: Comparing the obtained results from branch and bound algorithm.

The number of problem	Number of machines	Number of cells	Maximum number of machines	Response		
				Genetic response time (seconds)	Branch and bound response time (second)	ARE
1	6	3	3	203	194	0.04
2	8	3	3	230	250	0.08
3	10	3	4	436	450	0.03
4	12	3	5	434	442	0.01
5	14	4	5	1053	1100	0.04
6	16	4	5	1899	2100	0.09
7	18	5	5	4049	4100	0.01
8	20	5	6	6560	6600	0.006

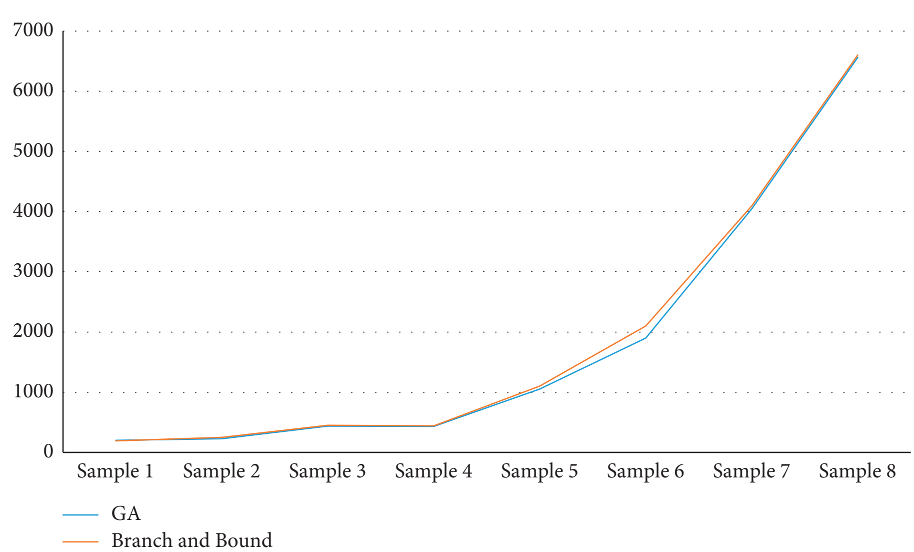

Figure 1: Comparison between GA and branch and bound.

in the academic world as future lines of research. Then, we proposed an integer mathematical programming. To solve mathematical programming, we introduced a branch and bound approach. Then, the proposed approach was formed with the genetic algorithm. The results shown for each sample are calculated to be less than 0.1, and the error difference between the results of the two algorithms is insignificant.

5. Managerial Insight

Most research done on the design of cellular production systems also has examined one of the main areas of design including cell formation, cellular layout, and material handling. Some researches also have been done by considering the lack of independence of these areas, two areas simultaneously and three areas sequentially. In addition, it is also considered in the models presented to solve the problems of cell formation and cell arrangement simultaneously. Many realistic situations of the workshop environment are not considered. In fact, in none of the studied models, the exact layout of machines within cells and cell layout are not determined in the workshop. In most models, only one of the cells or intercells is solved, and the output of the model solution is a sequence of cells or machines.

6. Conclusion

In the research conducted in the design of cell production systems, interactions such as cell formation, arrangement, and management systems have been neglected. In addition, the research that simultaneously considers the cell formation and cell layout does not consider the real situation of workshop. In the present study, the comprehensive mathematical framework for designing the cellular production systems together with the solution algorithm is presented.

The main goal of this research is to present a mathematical framework for designing and also providing the efficient methods for solving the desired problem. Therefore, the main contribution of this paper is to determine the same component according to the characteristics of designs and production requirements. This study includes a different approach in integrated design of cellular production system. In this approach, by considering the material handling system, cell formation and cellular layout are investigated separate from intracellular layout. Intercellular layout is considered as the production lone and material handling systems. A branch and bound algorithm is also provided to solve this problem. The performance of provide algorithm and the performance of provided approach are investigated by using different numerical samples. The results show the performance of the provided algorithm and approach in design of cellular production systems. So first the mathematical linear model is provided as the integrated problem of cell formation, intracellular layout, and designing the material handling systems by minimizing inter-cell flow. The main results of the paper are as follows:

(i) The proposed model can calculate the best value of the objective function by considering the number of machines, the number of cells, and the maximum number of machines

(ii) The proposed model has a significant difference in terms of computational time compared to the genetic algorithm

(iii) Due to the slight difference between the proposed model and the genetic algorithm, with increasing computational time, we can use the genetic algorithm as it determines the optimal response in less time

For further research, given that we encounter uncertain parameters in the real world, we can get closer to the real world by applying uncertainty in modelling.

Data Availability

Data are available upon reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Explaining the Effective Factors on Digital Transformation Strategies in the Telecom Industry of Iran Using the Delphi Method

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Digital transformation is emerging as the main driver of widespread change in the world around us. The communications industry is at the forefront of this transformation, both as an industry that is witnessing extensive changes in its market environment and as a major driver of digitalization around the world. The use of technology and the achievements of information technology alone will not lead to digital transformation in the organization because digital transformation is something of a strategy. The purpose of the research is exploratory and the type of applied research. The research method is data analysis, integrated, quantitative, and qualitative. The Delphi method has been used to identify the indicators, and the fuzzy DANP technique has been used to prioritize and affect. In this research, components and indicators of digital evolution have been extracted using qualitative content analysis. For this purpose, library studies including books and articles, structured interviews with industry experts, the content presented in domestic and foreign conferences and lectures, and reference models provided by leading organizations in the industry were used. The components and indicators were approved by the Delphi method, and the relationship between the components and the indicators and their ranking was done using the DANP (DEMTEL-ANP (DANP)) method. In the end, 6 components and 20 indicators were finalized and identified as indicators of high importance.

1. Introduction

The global connectivity trends provide people with access to all of their business and social activities, from simple instant messaging to global currency transactions on demand. To have a successful digital transformation program today, a business must have a proper understanding of digital strategy and operating model and must be actively involved in the increasingly competitive digital market in the face of increasing digital change instead of a passive approach. In recent years, powerful forces such as technical capabilities, legal requirements, population changes, and the economy have made significant changes to the business model [1].

The telecom industry has experienced rapid changes worldwide as the share of data and the revenue of operators increases. Although indexes of Iran are still lower than the rest of the world in terms of mobile and mobile bandwidth development, it has grown rapidly in recent years, providing a great opportunity for current and potential new entrants. It has created the largest markets in the Middle East. With the implementation of global technology in Iran and the improvement of the domestic situation in this country, Iran with the potential and significant increase in the share of ICT in GDP can be on the verge of a significant digital transformation. Years ago, a country like Iran was far from the latest technology in the world. Today, when we talk about digital technologies, the previous gap from the first level of the world is no longer conceivable. According to statistics published in 2018, the Internet penetration rate in the world was 53%, while the same figure in the country was about 70%

[2]. Emerging general technologies such as the latest mobile phones and hardware are also available shortly after the global markets in Iran. The existing frameworks for implementing a digital transformation are too general, essentially as a set of best practices and recommendations, rather than a systematic approach that presents the conventional structure and concerns. Based on this, we can say that digital strategy is equal to business strategy in terms of scope and scale of impact, and the basic principles that were set at the beginning are also true for it, but in terms of speed of responding to environmental changes, how to design and implement it is completely different. However, research shows that many organizations have not yet realized this and have not taken serious action. According to a 2016 Harvard Business Review survey, only 47% of organizations have formally formulated a business strategy for their digital future, which is a matter of great concern.

In view of the above, many studies should be done to prepare an accurate and complete model for the development of information technology strategies in the telecom industry transformation program and put on the agenda. The main problem is the lack of a custom and indigenous framework for categorizing and identifying areas that need to be changed and vital telecommunication systems to implement digital transformation in various dimensions and themes in this field. However, "digitalization" has found its way into corporate strategy, and the need for digital transformation is well understood. We do not fully understand how to implement this change. The key question is how to take advantage of digital developments in the telecom industry in Iran. And what can be the model of digital transformation strategies in the telecom industry?

1.1. Theoretical Gap. According to the mentioned cases and the current state of the art, numerous studies are required to be accomplished for the preparation and implementation of an accurate and complete model for the development of a digital transformation strategy in the telecom industry. The existing frameworks present the conventional structure and concerns with a general collection of the best practices and recommendations, rather than a systematic approach to implementation of the digital transformation model. The main problem is due to the lack of a custom and indigenous framework to categorize and identify the main vital and dynamically changing areas in telecom systems to implement digital transformation in various dimensions and criteria. However, "digitalization" has found its way into corporate strategy, and the need for digital transformation is well understood. But the method of implementing this change is not trivial [3]

The key question is how to take advantage of digital developments in the telecom industry in Iran. And how can develop a model of digital transformation strategies for the Iranian telecom industry?

1.2. Innovation in Research. Digital transformation is a new topic that has been seriously discussed in the world since 2014. Most of the articles in this field have been published since 2017, and the course of studies in this field is increasing rapidly. It is still a novel topic in the field of telecom research in Iran. The subject literature of digital transformation is under exploration by Iranian researchers, and according to the authors' knowledge and review, no deep studies have been conducted in this field. On the other side, the global and international research have focused on theoretical aspects.

In this study, the categories, indicators, and components in the field of digital transformation have been analyzed, and based on the Delphi approach, the main components of the Iranian telecom industry are selected and prioritized. Various data gathering methods including prepared questionnaires and semistructured interviews and surveys are employed by the experts who had deep experience and knowledge about the conditions and infrastructure of the telecom industry in the country. The expert's points of view and opinions were employed for the successful implementation of digital transformation in the telecom industry. In the next step, the fuzzy DANP technique has been applied to impacts, effectiveness, prioritization, and ranking of indicators and components. According to our knowledge, this approach has never been done in any study in any country. In addition, the approach and its results can be considered as a basement for continuing further studies in the field of digital transformation for other industries and for other countries.

1.3. Importance and Necessity of Research. Digital transformation refers to the use of digital technologies in all parts of a business, especially changing the way they process and transfer value to customers. On the other hand, digital transformation is a cultural change that constantly challenges the current state of the organization and the past experiences of personnel. Digital technology is improving the performance of companies based on the approach of process change. Digital is now a vital subject for an organization to survive in a competitive world [4].

The five main drivers of digital transformation are listed as follows:

(i) Strong communication with customers
(ii) Business agility
(iii) Operational efficiency and cost reduction
(iv) Innovation in services
(v) Growth opportunities

In this dynamic era where fast change is a default paradigm and the situation where competitors cannot be clearly analyzed and new technologies are emerging every moment, the classical process, analysis, planning, and implementation are not very efficient. In many industries and companies, digital technologies have revolutionized business strategies, processes, and capabilities. In this condition, organizations must use novel management methods to coordinate and overcome these changes. The approach used for this purpose is to develop a digital strategy that is used to integrate all interactions and actions and take advantage of digital developments in the organization [3]

A digital strategy helps the organization to align all digital activities in the organization with business goals. Therefore, all activities performed in the organization are related to digital strategy. To have this strategy, all the dimensions of the business that are being changed by transformational technologies must be examined and analyzed. This means that new decisions must be made in order to maximize the opportunities created in addition to reducing the risks posed by these technologies.

Given this, we can express that digital strategy is equal to business strategy in terms of scope and scale of impact, and the basic principles that were set at the beginning are also true for it, but in terms of speed of response to environmental changes, formulation process and implementation are completely different.

To survive in this digital age, organizations must develop and implement such a digital strategy and insure themselves against the probable risks of rapid changes in this age. The main factors that lead today's organizations to adopt digital strategy are as follows [5]:

(i) The importance of innovation in products and services
(ii) The need to provide digital services
(iii) Rapid advances in the digital environment
(iv) Risk optimization
(v) Increase control
(vi) Customer experience management

Digitalization will emerge dramatically in the coming decade with features that are different from the past, and organizations operating in the industry must be prepared to take advantage of the vast changes that are taking place in consumers lifestyles, the activities of companies, and economic models.

The increasing availability of technologies such as mobile phones, artificial intelligence, cloud computing, analytics, and platforms has dramatically changed the way we live, work, and communicate, a phenomenon known as the Fourth Industrial Revolution. The telecom industry is playing an important role in shaping this digital revolution [5].

The telecom ecosystem has provided the basic requirements, such as access, internal communications, and applications, needed to achieve such a revolution. Much of the potential value of digitalization across industries around the world in the next decade will go to the telecom industry, which provides the essential infrastructure, applications, and productivity improvement programs in many sectors [6].

In the following, in Section 2, the theoretical foundations and research literature are examined. Section 3 describes the research method and how the data were collected. Section 4 analyzes the data, and Section 5 presents the research conclusions.

2. Literature Review

2.1. Theoretical Foundations. Information and communication technology is considered to be one of the key technologies in developed countries, so countries with smart industrial policies for the development of the information technology industry will be able to take advantage of it as one of the largest and fastest-growing industries in the world. It is obvious that the share of each country in the benefits of this industry is directly related to the native capacity of that country in this field [7]. The main features of the telecom industry are as follows.

The trend of dominant technologies in this industry is very fast, and it can even be said that after the software industry, it is the highest speed of technology development in this industry. These approaches require extensive research and strong technological support [8]. The key importance of this industry is not limited to its economic dimensions. The high level of technological capabilities and close communication between this industry and other industries also leads to technology overflow in technical fields [9]. Due to the growing population of the world and the need to provide a clean environment, today, developed countries by developing programs tailored to this need to move industries and factories that pollute the environment from the interior and turn to green industries. The telecom industry is also one of the green industries due to its characteristics and use of superior technology, which has provided the growing need of the world for a wide market [10]. If the information exchange space and the use of information and communication technology are valued in a country, its direct impact can be seen with the proper functioning and security of the information space in daily life. It is noteworthy that all the officials of the country have many security concerns. The strength of the work is the existence of these concerns and the belief of all top officials to use internal power to address these concerns, which should be institutionalized by providing long-term decisions to localize the industry [11]. The value chain of the telecom industry is shown in Figure 1.

The goal of the Fourth Industrial Revolution is to create and use technologies that are capable of doing things beyond human ability. It is the core of the creation of many new industries and the survival of many of them and is possible only with a complete digital transformation [13]. Digital transformation is a set of profound transformations and changes in organizations and businesses, which allow them to take advantage of the opportunities arising from the development and promotion of technology and the resulting changes in their development in human societies and use them in line with strategies and priorities. Benefit yourself [14]. The exact definition of the term digitization is very important because it is easily confused and is often confused with the term digitization in the literature. Gartner defines digitization as "the process of changing from analog to digital" [15]. Digitization is defined as follows: "The use of digital technologies to change a business model and provide new opportunities to generate revenue and value is the process of transition to a digital business" [15]. Digitization goes beyond a technical process of encrypting all types of information in digital format.

2.2. Previous Study. Aghimin et al. [16] examined the critical success factors for digital participation of construction organizations. Construction companies in developing

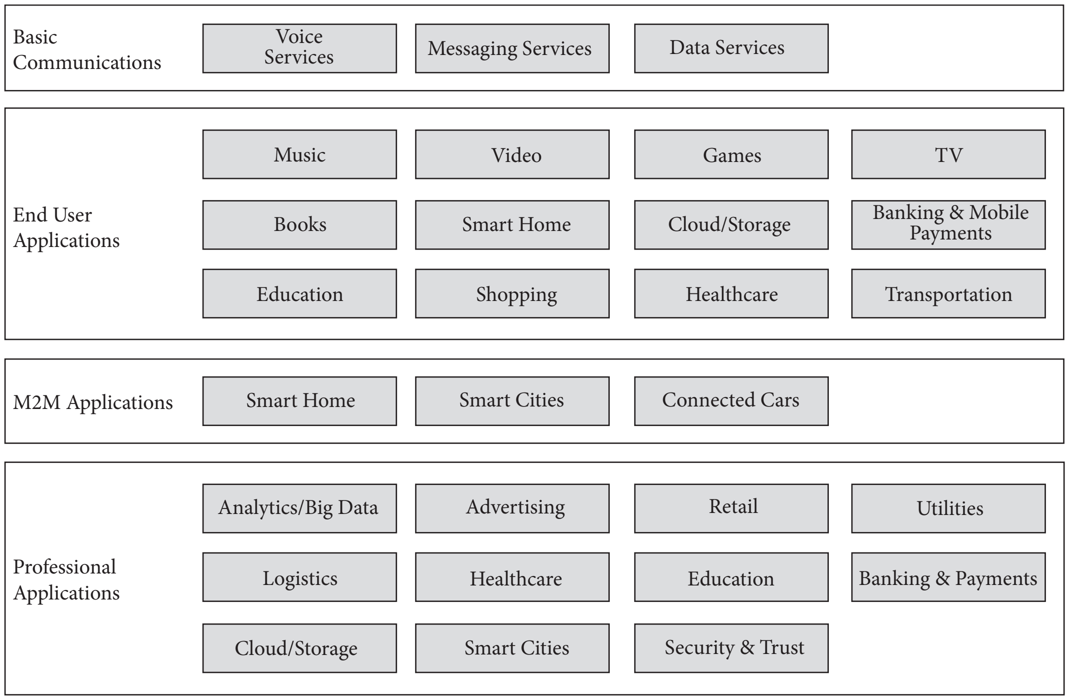

Figure 1: Telecom value chain [12].

countries are lagging behind in the use of digital technology. Hence, poor project delivery and technology backlog are still evident. In this study, the findings show that trust in digital partners, top management support, and digital partner selection are the three main success factors for participation. Other factors that can be considered along with these main factors are creating a common goal, a long-term commitment, effective communication, appropriate conflict resolution and structure, as well as continuous digital training, workshops, and meetings [16]. Melovic et al. [17] examine the impact of digital transformation and digital marketing on brand promotion, positioning, and e-commerce in Montenegro. By defining the impact of this concept on brand promotion and positioning, that is, the development of e-commerce through e-services, this paper examines the digital transformation methods in Montenegro influencing the use of digital marketing in business. The results show that a number of factors determine the methods of companies using digital marketing and the use of different levels of influence, including the implementation period, the ability of responsible people to use it, understanding the cost-effectiveness of digital marketing, and measurable. In addition, the results show that the more a company trusts the use of digital marketing in its business, the more important its impact on brand promotion and positioning [17]. Bossdekis and Cardaras [18] examine the digital evolution of local government: a case study from Greece. Digital transformation in the public sector means new ways of working with stakeholders, creating new service delivery frameworks, and creating new forms of relationships. This paper presents a research based on empirical data with the aim of identifying the current situation and potential for digital transformation in municipalities. This is a case study from Greece, and based on the results, it identifies the challenges of using digital technologies in the public sector, especially in local governments, and concludes on the steps taken for digital transformation [18]. Gabonenko et al. [19] examine value management in the digital transformation strategies of Russian companies and the Fourth Industrial Revolution. The purpose of this work is to define the impact of management on values on the transformation processes of digital business and then determine what digital or conventional technologies are used to increase the value of companies. This study has proven that as the digital transformation progresses and value-driven management makes digital transformation more efficient, the use of different digital technologies in management is worthwhile [19]. Reference [20] evaluated the critical success factors for smart mobility systems (SM) and assesses its current application level for smart city development using Nigeria as a case study. This study is based on a mixed-method approach (Delphi and quantitative survey). The study revealed seven critical success factors of smart mobility. Furthermore, the findings of this study revealed that factors such as sustainable, innovative, and safe transportation system; availability of ICT infrastructure; local accessibility of transportation infrastructure; and availability of transportation infrastructure (bike, cycling, and pedestrian mobility facilities) are the most significant smart mobility success factors. Also, a good consensus was achieved for all the success factors. Tjebane et al. [21] identified organizational factors imperative to driving the adoption of AI in construction organizations. The study uses a quantitative survey approach to collect data through snowball sampling of industry experts on factors associated with AI adoption. With data from 169 respondents, exploratory factor analysis was adopted to identify critical organizational factors to ease AI adoption in the industry. Furthermore, confirmatory factor analysis was employed to demonstrate the relationship among the constructs. Ikuabe et al. [22] assessed the performance measurement indicators that influence the uptake of cyber-physical systems (CPS) for facilities management (FM) functions. Using a structured questionnaire, data were collected from built environment professionals in the Gauteng province of South Africa. Data collected was analyzed using a five-stage process that includes data reliability and validity, descriptive statistics, establishing a difference in groups' opinion, principal component analysis, and model testing and fit statistics for confirmatory factor analysis. Shojaei et al. [23] identified and described how enabling factors are implemented by large UK contractor firms to transform their organizations using building information modelling (BIM) for projects. For this purpose, a qualitative exploratory approach is employed in this paper. Data are gathered through 42 semistructured interviews with professionals in strategic and management roles in construction companies in the UK, followed by case studies of five leading main contractor companies selected to provide examples of how they implemented the identified enablers.

2.3. Research Gap. In this research, due to adopting a multifaceted approach to designing the digital transformation strategy model and trying to explain the phenomenon in the real context, the positivist paradigm has been used. Scientific limits and methods are considered. The ontology of the positivist paradigm of claiming to rely on universal laws and facts explains social phenomena. In methodology, too, positivism is based on observable and testable facts. This theory is rooted in the ideas of Newton, Descartes, and Kent, who established and validated positivism as a means of understanding the social world. Also, due to the use of in-depth interviews and case studies, the interpretive paradigm has been used to describe more precisely the meaning that has occurred. In the interpretive paradigm, the relationship between variables cannot be expressed by numbers and is a space for expression, explanation, and interpretation. Interpretive ontology sees the world as a structure composed of multiple realities and works naturally from the inductive approach (except to the whole) to explain the phenomenon under study. Communication with the interview of the listeners is subjective and does not rely solely on receiving the subjects' mindsets through questionnaires, and on the contrary, the positivist paradigm that seeks to understand the phenomenon from an external perspective understands the phenomenon from an internal perspective. The inner gaze identifies multiple realities because the views of all actors are considered and valued equally. Figure 2 shows the steps of conducting research. Also, Table 1 categorized the previous studies.

3. Research Methodology

Since quantitative and qualitative research methods alone cannot study the complexities of the issues and constituent elements, in this study, a combination of these approaches (mixed research) has been used. This study aims to identify the components and indicators needed to develop a digital transformation strategy in the telecom industry in accordance with the needs and current situation of the country and provide a local model for it. The time frame of this research is from the summer of 2020 to the fall of 2020. The spatial scope of this research is the Ministry of Information Technology and its affiliated organizations in Tehran. The objectives of this research are to identify the dimensions and main components of digital transformation in the telecom industry and to determine the priority and weight of the main components of digital transformation in the telecom industry in Iran.

3.1. Qualitative Content Analysis. This phase began with the initial collection of information and the development of the concept and the collection of information in a round trip in order to find resources to answer the research question. In the coding process, the raw information is regularly transformed into units for accurately describing the properties of the content, during which the research text is reviewed, listened to, or read, and the number (code) of each category according to the coding instruction and enters in the tab. The next step involves inferring the specified themes or categories and their properties. In this stage of the research, the inference is derived from the data, and the meanings derived from the data are reconstructed. The activities of this section include the properties and dimensions of the classes, determining the relationships between the classes, clarifying the patterns, and testing the classes against all the data. In open coding, the analysis process, the concepts identified, and their characteristics and dimensions are discovered in the data [6]. In other words, in this type of coding, the concepts within the interviews and the documents are classified based on the connection with similar topics. It forms the primary categories of information about the phenomenon under study by segmenting the information. "Concepts" are the basic units or microanalysis because it is from the mental imagery and conceptualization of data that theory is formed, not from the actual data itself [24]. Categories are more abstract and show a higher level of comparison with concepts. They are produced through the same analytical process of making comparisons to highlight similarities and differences, which are used at a lower level to produce the concepts used.

The statistical population of this study includes two categories of academic experts and industrial experts as follows:

(i) Academic experts: faculty professors and PhD researchers have articles and books in the field (information technology, strategy, and digital transformation)

(ii) Students and graduates: educated in management (information technology and industry), engineering (computer, information technology, and industry), and related fields

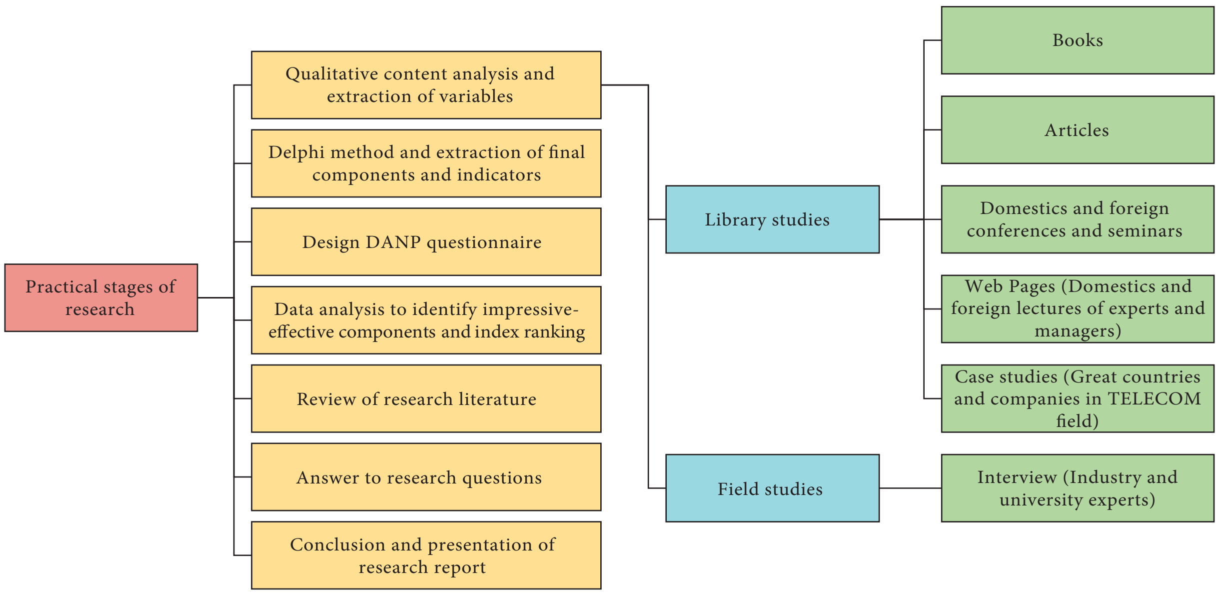

Figure 2: The research conceptual model.

Table 1: Categorized studies.

Authors	Goal	Application	Key factor
Aghmin et al. [16]	Examined critical success	Construction organization	TrustTop management support digital partner
Melovic et al. [17]	Examined impact of digital transformation	Digital marketing on brand promotion	E-commerce e-service
Bossdekis and Cardanas [18]	Examined digital evaluation of local government	Digital transformation in the public sector	Service delivery
Gabonenko et al. [19]	Examined value management in the digital transformation strategies	Russian companies	Digital business conventional technologies
Okafar et al. [20]	Evaluated the critical success factor	Smart mobility system	Sustainable innovative safe transportation system availability of ICT

(iii) Industry experts: senior and middle managers and consultants in the field of telecom and information technology managers with at least 5 years of work experience in the field of information technology

The sampling method in the qualitative part will be purposeful or judgmental. The concept of targeted sampling and snowball is used in qualitative research, and it means that the scanner selects people and study place because it can be effective in understanding the research problem and the central phenomenon of the study.

3.1.1. DANP. A fuzzy approach is used to deal with the uncertainty and ambiguity in respondents' verbal expressions. Since, in most decisions, the elements interact with each other and there are relationships and interdependencies between decision options and decision criteria and one of the goals of most research is to prioritize and identify complex interactions between them, the network analysis method (ANP) is a good method. Each cluster of criteria has the same effect, if according to the results obtained from the Demetel technique, there are different degrees of effectiveness between the criteria and, consequently, between the clusters consisting of criteria. Therefore, to solve this problem, the network analysis method (ANP) based on the DEMATEL technique, which is called DANP, has been used.

3.2. Delphi Method. The questions of the first questionnaire are in fact the same identified indicators or factors. The results showed that the experts have a common understanding of the subject and questions of the questionnaire, which indicates the validity of the questionnaire structure. In this study, based on the amount of skewness and skewness of the data, we have examined the normality of the data and the table below presents the skewness and skewness of the first questionnaire. As can be seen, the statistic values for the skewness and elongation index are as follows (2 and 2, respectively), so it is possible to accept the normality of the data related to each question and confirm the reliability of the questionnaire. The average of experts' opinions is used to identify important indicators. In other words, indicators or questions whose average value of expert opinions is greater than 3.5 are known as important and effective indicators, and indicators with questions for which the average value of expert opinions is less than this amount are considered as ineffective or insignificant indicators are known. The purpose of realization is only to identify important and effective indicators. Therefore, in the research, insignificant indicators are eliminated.

At this stage, first, the questionnaires distributed among the experts were collected. After collecting the questionnaires, 14 questionnaires were returned out of 20 distributed questionnaires. Due to the size of the file, the completed questionnaires of the experts were refused one by one. After collecting the completed questionnaires of the first round, which was 14 questionnaires, the aggregation and the average opinions of experts are calculated, and based on the opinions of experts and the average opinions of experts, the analysis is performed. Table 2 summarizes the opinions of experts along with their mean and standard deviation.

Examination of the results of Delphi courses shows that the average of questions has increased and the standard deviation of questions has decreased, which indicates that the results have improved and the theoretical consensus of participants has increased. In the end, 20 indicators were finalized and identified as high-importance indicators.

3.3. Solution Approach

Step 1. Direct-influence matrix calculation: in this step, the respondents were asked to show the effect of criterion i on criterion j using Table 2. In this work, for data analysis, the opinions of $p = 8$ experts were gathered. For calculation of this matrix, triangular fuzzy number $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is evaluated. To take into account the opinion of experts according to the following equation, an arithmetic mean is taken from them:

$$\tilde{z} = \frac{\tilde{x}^1 \oplus \tilde{x}^2 \oplus \tilde{x}^3 \oplus \ldots \oplus x^p}{p}. \quad (1)$$

where p is the number of experts; $\tilde{x}^1$, $\tilde{x}^2$, and $\tilde{x}^p$ are the pairwise comparison matrix of expert 1, expert 2, and expert p, respectively; and $\tilde{z}$ is a triangular fuzzy number in the form $\tilde{z}_{ij} = (l'_{ij}, m'_{ij}, u'_{ij})$.

Step 2. Direct-influence matrix normalization: to normalize the matrix obtained from the previous step, use the following formulas and call it the H matrix.

$$\begin{aligned}\tilde{H}_{ij} &= \frac{\tilde{z}_{ij}}{r} = \left(\frac{l'_{ij}}{r}, \frac{m'_{ij}}{r}, \frac{u'_{ij}}{r}\right) \\ &= \left(l''_{ij}, m''_{ij}, u''_{ij}\right),\end{aligned} \quad (2)$$

where r is obtained from the following relation:

$$r = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u'_{ij}, \sum_{i=1}^{n} u'_{ij}\right). \quad (3)$$

Step 3. Total-influential matrix (TC) calculation: after calculating the normal matrix, the fuzzy total-influential matrix is obtained according to formulas (4) to (7).

$$T = \lim_{k\longrightarrow+\infty}\left(\tilde{H}^1 \oplus \tilde{H}^2 \oplus \ldots \oplus \tilde{H}^k\right). \quad (4)$$

Each element is a fuzzy number $\tilde{t}_{ij} = (l^t_{ij}, m^t_{ij}, u^t_{ij})$ and is calculated by the following formulas:

$$\left[l^t_{ij}\right] = H_l \times (I - H_l)^{-1}, \quad (5)$$

$$\left[m^t_{ij}\right] = H_m \times (I - H_m)^{-1}, \quad (6)$$

$$\left[u^t_{ij}\right] = H_u \times (I - H_u)^{-1}, \quad (7)$$

where I matrix is the identity matrix and H_l, H_m, H_u. Each matrix is $n \times n$. Its constituents are the lower number, the middle number, and the upper number of the triangular fuzzy numbers of the H matrix.

Step 4. Calculate the total-influential matrix: first, the T_D matrix must be extracted from the total-influential matrix of the T_c criteria. Therefore, each T_D matrix element can be calculated as follows: if we know every T_D matrix element is t_{ij}, every t''_{ij} is obtained from the mean of every T_C^{ij}.

Step 5. Calculate the intensity and direction of the effect: according to equations (8) and (9), the r_i and c_j indices are calculated. The r_i index represents the sum of the i^{th} row, and the c_j index represents the sum of the j^{th} column of the T_c matrix for the corresponding dimension. Similarly, we calculate the values of the index $\tilde{R}$ and $\tilde{D}$. The R_i index represents the sum of the i^{th} row, and the C_j index represents the sum of the j^{th} column of the T_D matrix. To draw and analyze the chart, we need two indicators of impact intensity and effectiveness and direction of impact, which are obtained using D_i and R_j. For each $i = j$, we will have:

$$\begin{aligned}\tilde{D} &= (\tilde{D}_i)_{n\times 1} \\ &= \left[\sum_{j=1}^{n} \tilde{T}_{ij}\right]_{n\times 1},\end{aligned} \quad (8)$$

$$\begin{aligned}\tilde{R} &= (\tilde{R}_i)_{1\times n} \\ &= \left[\sum_{i=1}^{n} \tilde{T}_{ij}\right]_{1\times n},\end{aligned} \quad (9)$$

where $\tilde{D}$ and $\tilde{R}$ are $n \times 1$ and $1 \times n$ matrices, respectively.

The next step characterized the importance of the indicators $(\tilde{D}_i + \tilde{R}_i)$ and the relationship between criteria $(\tilde{D}_i - \tilde{R}_i)$. If $\tilde{D}_i - \tilde{R}_i > 0$; the relevant criterion is effective; and if $\tilde{D}_i - \tilde{R}_i < 0$, the relevant criterion is effective.

(i) $\tilde{D}_i + \tilde{R}_i$ = intensity of impact and effectiveness. (In other words, the higher the value of $\tilde{D}_i + \tilde{R}_j$, the more it interacts with other factors in the system.)

(ii) $\tilde{D}_i - \tilde{R}_i$ = direction of impact and effectiveness. (Thus, if $\tilde{D}_i - \tilde{R}_j > 0$, the relevant criterion is the cause, and if $\tilde{D}_i - \tilde{R}_j < 0$, the relevant criterion is the effect).

Table 2: Summarizing expert opinions.

Criteria	Code	Subcriteria	1	2	3	4	5	Ave 1	Ave 2	Ave 3	O_1	O_2	O_3
Customer	CU2	Customer experience	0	0	0	6	8	3.71	4.07	4.57	1.14	0.93	0.70
	CU3	Customer touch point	0	0	0	8	6	3.64	3.86	4.43	0.93	0.81	0.65
	CU4	Customer insight	0	0	4	5	5	3.64	3.64	4.07	1.29	0.99	0.87
Business model	BM1	Digitally modified system	0	0	1	5	8	4.36	4.43	4.50	0.74	0.67	0.63
	BM2	New digital business	0	0	1	7	6	4.21	4.29	4.36	0.78	0.76	0.72
Culture	CUL1	Train	0	0	0	4	10	4.71	4.71	4.71	0.36	0.28	0.28
	CUL2	Awareness	0	0	0	2	12	4.86	4.86	4.86	0.83	0.83	0.83
	CUL3	Organizational mindset	0	0	4	6	4	3.93	3.93	4.00	0.84	0.79	0.71
Workforce	WO1	Digital skills	0	0	0	6	8	4.43	4.43	4.57	0.83	0.83	0.80
	WO2	Mindset	0	0	0	8	6	4.36	4.36	4.43	0.63	0.63	0.60
	WO3	New talent and creativity	0	0	0	9	5	3.93	4.07	4.36	1.07	0.98	0.88
Governance	GO1	Leadership	0	0	2	4	8	4.36	4.36	4.43	0.84	0.84	0.79
	GO2	Policy	0	0	0	5	9	4.50	4.50	4.64	0.76	0.76	0.74
	GO3	Policies and rules and regulations	0	0	0	7	7	4.43	4.50	4.50	0.65	0.59	0.59
	GO4	Sustainability (environmental, social, and economic)	0	0	2	4	8	4.43	4.43	4.43	0.67	0.67	0.67
	GO5	Operation	0	0	0	6	8	4.57	4.57	4.57	0.93	0.71	0.71
	GO6	Agile	0	0	0	4	10	4.64	4.64	4.71	0.28	0.21	0.21
Technology	TEC1	Infrastructure (spatial technologies, virtualization, SDN/NFV, 5G, cloud, and quantum processors)	0	0	1	4	9	4.57	4.57	4.57	0.65	0.65	0.65
	TEC2	Applications (open architecture, microservices, etc.)	0	0	3	3	8	4.36	4.36	4.36	0.84	0.84	0.84
	TEC3	New technology trends (blockchain, IoT, 3D printers, UAVs, etc.); cognitive technologies (artificial intelligence, machine learning, robotics, and natural language processing); digital reality (augmented reality and virtual reality)	0	0	0	6	8	4.57	4.57	4.57	0.51	0.51	0.51
	TEC4	Security (identification tools, cyber security, etc.)	0	0	1	4	9	4.57	4.57	4.57	0.65	0.64	0.64
	TEC5	Data (data sovereignty, etc.)	0	0	0	12	2	3.57	3.57	4.14	0.65	0.65	0.65
	TEC6	Communication (social networks, etc.)	0	0	0	10	4	3.64	3.64	4.29	0.63	0.63	0.63

According to the calculated values, the values of $\widetilde{D}_i + \widetilde{R}_i$ and $\widetilde{D}_i - \widetilde{R}_i$ indexes for the criteria and also the indexes $\widetilde{D}_i + \widetilde{R}_i$ and $\widetilde{D}_i - \widetilde{R}_i$ are obtained for the dimensions, and then defuzzification is calculated using the following equation:

$$\text{defuzzy} = \frac{((u-l)+(m-l))}{3} + l. \tag{10}$$

Step 6. Normalization of the total-influential matrix ($\mathbf{T}_\mathbf{D}^{\propto}$): for normalization of total-influential matrix, the matrix is separated into three tables with lower, middle, and higher bounds. Then, for all bound, each element is divided by the sum of all elements in the row. After that, the matrix is transposed. In our use case, the results are shown in Table 3.

Step 7. Normalization of total-influential matrix $\mathbf{T}_\mathbf{C}^{\propto}$ criteria and formation of an unbalanced supermatrix: we normalize the T_c matrix using the sum of each row T_C^{ij} calculated according to the relevant dimension, and then in each T_C^{ij}, each element is divided by the sum of the elements of the corresponding row. By transposing the matrix $T_C^{\propto}$, an unbalanced supermatrix is obtained.

Step 8. Formation of a balanced supermatrix: in this step, we multiply the matrix $T_D^{\propto}$ by the matrix W. In this way, each $t_D^{\propto ij}$ is multiplied by W_{ij}.

Step 9. Limit the rhythmic supermatrix: according to equation (11), bring the rhythmic supermatrix to power (consecutive odd numbers) so that all the numbers in each row converge:

$$\lim_{Z\longrightarrow\infty}\left(W^{\propto l}\right)^Z, \lim_{Z\longrightarrow\infty}\left(W^{\propto m}\right)^Z, \lim_{Z\longrightarrow\infty}\left(W^{\propto u}\right)^Z. \tag{11}$$

Step 10. Calculation of Weights and Priorities: in this step, by using equation (10), an exact value is resulted from the limited supermatrix. The weight of main factors is calculated from the sum of its subfactors. The results are shown in Table 4.

4. Results

In this study, using literature review and research background, research factors and components were enumerated. The main factors include 6 main criteria and 20 subcriteria, which are listed in Table 5 of these factors.

According to steps 1 and 2, total-influential matrix (T_C) calculation is shown in Table 6. T_c calculation is necessary. Because, we can calculate relation pattern of T_C matrix. In Tables 7 and 3, relation patterns of T_c matrix are shown based on step 4.

Table 3: Pattern of causal relations of T_D matrix.

	Di	Ri	$(Di)^{defuzzy}$	$(Ri)^{defuzzy}$	Di + Ri	Di – Ri
C1	(0.224, 0.671, 1.968)	(0.274, 0.762, 2.118)	0.955	1.051	2.006	−0.097
C2	(0.297, 0.801, 2.138)	(0.29, 0.788, 2.14)	1.079	1.073	2.151	0.006
C3	(0.306, 0.84, 2.327)	(0.266, 0.773, 2.271)	1.158	1.103	2.261	0.054
C4	(0.208, 0.695, 2.289)	(0.241, 0.754, 2.36)	1.064	1.118	2.182	−0.054
C5	(0.307, 0.854, 2.417)	(0.255, 0.766, 2.308)	1.193	1.110	2.303	0.083
C6	(0.28, 0.793, 2.28)	(0.296, 0.811, 2.223)	1.118	1.110	2.227	0.008

Table 4: Normal correlation matrix of complete dimensions.

	C1	C2	C3	C4	C5	C6
C1	(0.149, 0.151, 0.154)	(0.179, 0.169, 0.16)	(0.186, 0.171, 0.159)	(0.165, 0.165, 0.159)	(0.162, 0.162, 0.158)	(0.164, 0.161, 0.156)
C2	(0.203, 0.176, 0.159)	(0.136, 0.149, 0.154)	(0.182, 0.172, 0.161)	(0.212, 0.181, 0.162)	(0.176, 0.171, 0.161)	(0.179, 0.169, 0.159)
C3	(0.161, 0.166, 0.169)	(0.168, 0.17, 0.171)	(0.144, 0.155, 0.166)	(0.195, 0.175, 0.171)	(0.168, 0.167, 0.169)	(0.159, 0.166, 0.169)
C4	(0.14, 0.164, 0.178)	(0.155, 0.165, 0.176)	(0.154, 0.164, 0.176)	(0.109, 0.141, 0.169)	(0.165, 0.169, 0.178)	(0.154, 0.165, 0.177)
C5	(0.157, 0.169, 0.175)	(0.169, 0.169, 0.173)	(0.156, 0.164, 0.172)	(0.151, 0.164, 0.172)	(0.137, 0.151, 0.166)	(0.175, 0.172, 0.175)
C6	(0.19, 0.175, 0.164)	(0.192, 0.178, 0.166)	(0.178, 0.174, 0.166)	(0.169, 0.173, 0.167)	(0.192, 0.179, 0.167)	(0.169, 0.167, 0.163)

Table 5: The main criteria and subcriteria in the study.

Criteria	Code	Subcriteria	Code
Customer	C1	Customer insight	C11
		Customer touch point	C12
		Customer experience	C13
Business model	C2	New digital business	C21
		Digitally modified system	C22
Culture	C3	Awareness	C31
		Train	C32
		Organizational mindset	C33
Workforce	C4	Mindset	C41
		New talent and creativity	C42
Technology	C5	New trend	C51
		Security	C52
		Infrastructure	C53
		Applications (game architecture, microservices, etc.)	C54
Governance	C6	Sustainability (environmental, social, and economic)	C61
		Leadership	C62
		Data (data sovereignty, etc.)	C63
		Operation	C64
		Policies and rules and regulations	C65
		Communication (social networks, etc.)	C66

Table 6: Total-influential matrix calculation.

	C1	C2	C3	C4	C5	C6
C1	(0.033, 0.102, 0.304)	(0.046, 0.118, 0.313)	(0.036, 0.111, 0.332)	(0.031, 0.11, 0.351)	(0.035, 0.113, 0.345)	(0.043, 0.117, 0.324)
C2	(0.053, 0.136, 0.342)	(0.04, 0.119, 0.329)	(0.05, 0.136, 0.366)	(0.046, 0.132, 0.377)	(0.05, 0.135, 0.369)	(0.057, 0.143, 0.355)
C3	(0.057, 0.143, 0.37)	(0.056, 0.145, 0.375)	(0.044, 0.13, 0.386)	(0.047, 0.138, 0.41)	(0.048, 0.138, 0.4)	(0.055, 0.146, 0.386)
C4	(0.034, 0.115, 0.364)	(0.042, 0.126, 0.372)	(0.04, 0.122, 0.391)	(0.23, 0.098, 0.387)	(0.031, 0.114, 0.394)	(0.035, 0.12, 0.381)
C5	(0.05, 0.139, 0.382)	(0.054, 0.146, 0.389)	(0.052, 0.143, 0.409)	(0.051, 0.145, 0.431)	(0.042, 0.129, 0.402)	(0.059, 0.153, 0.404)
C6	(0.046, 0.128, 0.356)	(0.05, 0.134, 0.362)	(0.045, 0.131, 0.386)	(0.043, 0.131, 0.405)	(0.049, 0.136, 0.398)	(0.047, 0.132, 0.372)

Based on calculated results in Tables 6 and 7, the network relation map is determined. The significant relationships are shown in Figure 3.

According to Figure 3, the factors mapped above X-axis have positive D-R values that show a net influence on other factors. Based on this process, C2, C3, C5, and C6 is categorized as cause factors. The effect factors are those with negative D-R value and influence by cause factors. In the figure, C1 and C4 are categorized in this group. Figure 4 shows the subcriteria.

For normalization of total-influential matrix, the matrix is separated into three tables with lower, middle, and higher

Table 7: T_c relational pattern of T_c matrix.

	Di	Ri	$(\text{Di})^{\text{defuzzy}}$	$(\text{Ri})^{\text{defuzzy}}$	Di + Ri	Di – Ri
C11	(0.103, 0.314, 0.94)	(0.094, 0.283, 0.831)	0.452	0.403	0.855	0.050
C12	(0.11, 0.317, 0.931)	(0.076, 0.277, 0.896)	0.453	0.416	0.869	0.036
C13	(0.088, 0.285, 0.864)	(0.13, 0.355, 1.008)	0.412	0.498	0.910	−0.086
C21	(0.084, 0.241, 0.635)	(0.079, 0.235, 0.655)	0.320	0.323	0.643	−0.003
C22	(0.078, 0.236, 0.681)	(0.082, 0.241, 0.661)	0.332	0.328	0.660	0.003
C31	(0.126, 0.39, 1.193)	(0.14, 0.404, 1.167)	0.570	0.570	1.140	−0.001
C32	(0.139, 0.393, 1.123)	(0.14, 0.397, 1.142)	0.552	0.560	1.111	−0.008
C33	(0.13, 0.389, 1.161)	(0.115, 0.371, 1.168)	0.560	0.552	1.112	0.009
C41	(0.06, 0.216, 0.801)	(0.03, 0.175, 0.746)	0.359	0.317	0.676	0.042
C42	(0.031, 0.177, 0.747)	(0.061, 0.218, 0.802)	0.318	0.360	0.679	−0.042
C51	(0.171, 0.514, 1.594)	(0.161, 0.493, 1.557)	0.760	0.737	1.497	0.022
C52	(0.173, 0.528, 1.565)	(0.163, 0.521, 1.647)	0.755	0.777	1.532	−0.022
C53	(0.181, 0.535, 1.676)	(0.166, 0.517, 1.605)	0.797	0.763	1.560	0.034
C54	(0.148, 0.493, 1.602)	(0.183, 0.538, 1.626)	0.747	0.782	1.530	−0.035
C61	(0.262, 0.72, 2.03)	(0.242, 0.723, 2.199)	1.004	1.055	2.059	−0.051
C62	(0.322, 0.877, 2.418)	(0.288, 0.814, 2.305)	1.206	1.136	2.341	0.070
C63	(0.34, 0.914, 2.463)	(0.293, 0.786, 2.201)	1.239	1.094	2.333	0.146
C64	(0.279, 0.778, 2.225)	(0.268, 0.778, 2.214)	1.094	1.087	2.181	0.008
C65	(0.261, 0.755, 2.237)	(0.333, 0.884, 2.379)	1.084	1.199	2.283	−0.114
C66	(0.242, 0.717, 2.035)	(0.281, 0.776, 2.11)	0.998	1.056	2.054	−0.058

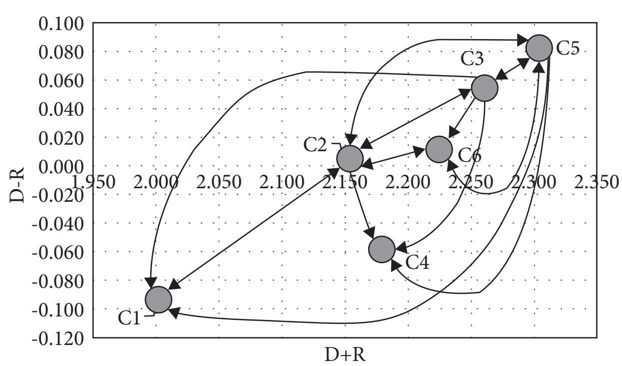

Figure 3: Causal diagram of the main criteria.

bounds. Then, for all bound, each element is divided by the sum of all elements in the row. After that, the matrix is transposed. In our use case, the results are shown in Table 4.

Finally, according to equation (10), an exact value is resulted from the limited supermatrix. The weight of main factors is calculated from sum of its subfactors. The results are shown in Table 8.

Based on the results summarized in Table 8, the first priority is governance with weight value of 0.174. The business model and culture are the second and third criteria with the weight value of 0.17 and 0.167, respectively. Technology, customer, and workforce are the 4th (0.165), 5th (0.163), and 6th (0.161) criterion. In Figure 5, the diagram of the main criteria weights is shown.

5. Discussion and Managerial Insights

Digital strategy in terms of scope and scale of impact is far beyond business strategy, and its basic principles are institutionalized at the highest levels of decision-making and decision-making in the highest authorities. The digital transformation plan can be considered as a roadmap for organizations for a comprehensive transformation with regard to digital transformations in the ecosystem governing the organization's space. According to Gartner, digital transformation consulting services are services provided to leaders, stakeholders, and senior executives of the organization to help upgrade digital technologies to create new opportunities and innovate the entire business and change components or all models of operations. Designing this roadmap is in itself a complex challenge that requires a deep and two-way understanding of the organization's business and digital age technologies. According to the majority of experts in this study, the need to pay serious attention to governance and legislation is a key requirement for the development and implementation of digital transformation in all industries and the telecom industry. Policy and rules and regulations of digital transformation based on the upstream documents of the strategy, roadmap, and vision of the organization and with regard to the macro development programs of the country is a basic necessity and needs to be seriously considered at the highest levels of decision making. In formulating policies and laws and regulations, in addition to the macro needs of the country and in line with international interactions, the risks and challenges of the path and scenarios to deal with them are also anticipated. Digital transformation in the communications industry generates $2 trillion in revenue for industry and society. Therefore, the need to establish the principles of digital transformation governance in the industry becomes more important. Digitalization has emerged dramatically in the coming decade with features that are different from the past, and organizations operating in the industry must be prepared to take advantage of the vast changes that are taking place in the way consumers live and the company's activities. And economic models will be created.

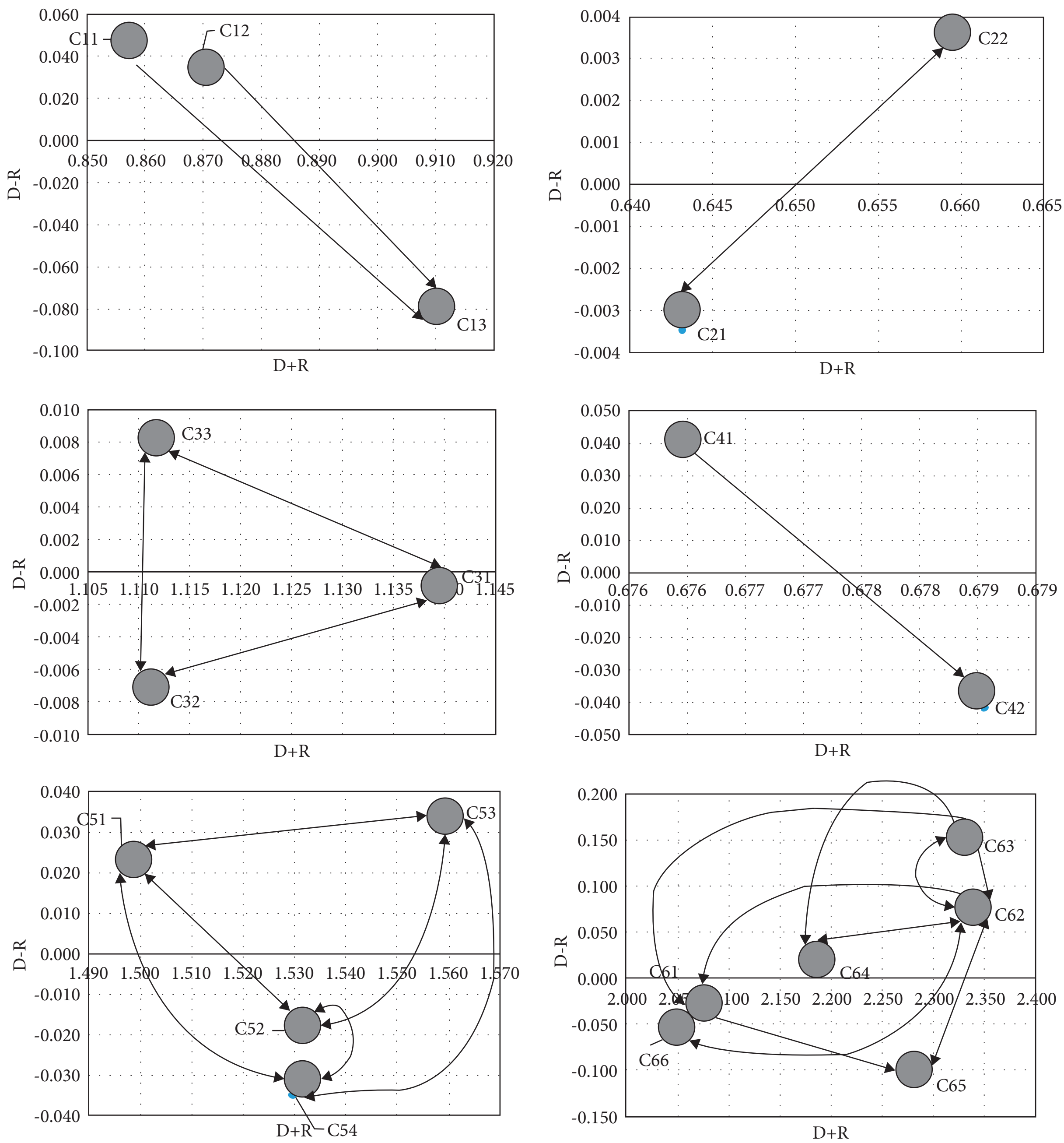

Figure 4: Causal diagram of subcriteria.

We need to know that digital transformation requires a shift in thinking to shift the focus of business models from product and service to problem-solving models and provide the realization of the digital revolution. Much of the potential value of digitalization around the world in the next decade will go to the telecom industry, which provides the necessary infrastructure, applications, and efficiency improvement programs in many sectors. Various industries such as retail industry, automotive industry, electricity industry, and so on are affected by the rules and regulations of the telecom industry. The industry faces a rapidly changing economic and competitive landscape that is driven by digital developments within and outside the industry.

Data strategy for digital transformation and the position of data governance requires a comprehensive approach. Data independence in data management, data control in data governance, data access in data mobility, and data-driven vision in data analysis are the main pillars of developing a suitable strategy for digital transformation. Paying attention to data and its ability to play a role in creating value is the focus of digital developments. Data as an organizational asset requires attention to data management requirements throughout the data life cycle. Undoubtedly, data governance is one of the most important and vital components of a data management program throughout the data life cycle, and perhaps that is why establishing a data

Table 8: Global factors weight.

Factors	Code	Weight
Customer	C1	0.163
	C11	0.321
	C12	0.325
	C13	0.354
Business model	**C2**	**0.170**
	C21	0.497
	C22	0.503
Culture	**C3**	**0.167**
	C31	0.351
	C32	0.334
	C33	0.315
Workforce	**C4**	**0.161**
	C41	0.466
	C42	0.534
Technology	**C5**	**0.165**
	C51	0.227
	C52	0.254
	C53	0.263
	C54	0.256
Governance	**C6**	**0.174**
	C61	0.145
	C62	0.179
	C63	0.154
	C64	0.171
	C65	0.180
	C66	0.170

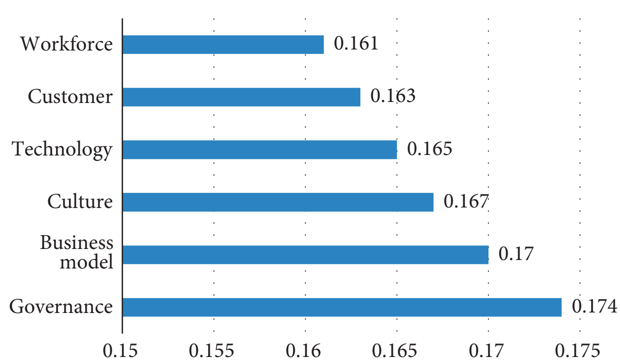

Figure 5: The weight of the main criteria.

governance program in many organizations is essential for the successful implementation of digital transformation. A strategy whose maturity level should be constantly monitored using data maturity models and moved towards its improvement and development.

Designing new interindustry business models in areas such as the internet of things will require extensive and agile networks that provide comprehensive coverage of customers and objects, software capabilities defined by the software, personal information protection and cyber flexibility, very low latency communications, and improved bandwidth. The research results show that the business model is very important in the successful realization and implementation of digital transformation. Changing business models from traditional to digital begins with the step-by-step modification of processes and progresses to digital transformation with the digitization of new business models. In short, digital transformation is not in emerging technologies but in the business model and operational model. However, the digitization of the industry requires changing existing policies and improving regulatory models. A prerequisite for developing a digital transformation strategy is to know the components of this strategy. One of the main prerequisites for developing such a strategy is to determine the relationship and how it affects the organization's business models. We need to know that digital transformation requires a shift in thinking to shift the focus of business models from product and service to problem-solving models.

The main task of cultural leadership for digital transformation is the responsibility of the most senior managers of the organization and the foundations of this great change must be formed from the context of culture and at the highest management levels. Senior managers of the telecom industry have a big role in drawing the digital vision of the organization, sharing the vision and involving the whole organization in creating change, creating technology leadership capabilities, and paving the way for changing the organizational culture to accept the great digital transformation. However, education is very important as one of the main subcriteria of culture, and managers' planning to understand digital realities for all organizational levels is inevitable. Research results show that the subcriterion of personal awareness and insight of employees is more important in digital transformation. Individual attitude and awareness of employees and identifying potential points for successful implementation of digital transformation increase the speed of change of acceptance culture far more than education. Although the role and effect of education are undeniable, in organizations where organizational thinking and its hierarchical structure are already well-formed, the role of awareness will undoubtedly be much deeper.

The telecom industry with its special features such as having advanced technologies with rapid changes, technology overflow in other industries, rapid rate of return on investment and job creation, and the high strategic importance of this industry in political and economic exchanges as a leader in exploiting emerging technologies understands the importance of this influential component in designing and formulating its macro strategies. IoT, cloud computing, mobile applications, social media, virtual and augmented reality, data analytics, artificial intelligence, and blockchain are some of the most important types of transformational technologies. These technologies will positively subvert business models, stakeholder experiences (such as customers and employees at the organizational level, and citizens at the national level), and operational processes.

Most telecom companies use the power of emerging technology to reuse their business models, rebuild market positions, and create creative offerings for customers and provide global currency transactions on demand. To have a successful digital transformation program, a business must have a good understanding of digital strategy and operating model and, instead of taking a passive approach to digital transformation, must be actively involved in the increasingly competitive digital market. A digital organization really needs to be innovative, in which case it is easy for customers to deal with it, and to move and adapt quickly.

Research results show that the digital transformation of the customer is one of the main pillars of designing strategy models in the telecom industry. The following effective criteria in the customer index from the point of view of Weber experts, based on the results of the analysis, are important and effective, including the customer experience, customer contact point, and customer insight.

The results show that the digital workforce is one of the main and influential components in the design and development of digital strategy. Jobs must employ and retain digital talent and promote a culture in which employees, temporary workers, and robots work together effectively. Lack of skilled talent is a challenge for businesses in finding and retaining the right talent. Creating a digital workforce is not limited to hiring and nurturing talent because there is a need to improve their workforce in other ways as well. Organizations that are thinking about change (digital, etc.) are constantly trying to attract external consultants, who often prescribe solutions with a single pattern to methods and organizations. The approach to creating change in the organization should be based on people within the company and have sufficient and deep knowledge about constructive and non-constructive solutions [25]. To achieve such ideals, employee thinking, which originates from the culture of the organization, is very important in achieving the goals of digital transformation. But there is new talent and creativity and digital skills, especially in organizations and industries. More tradition should be on the agenda as an irreplaceable priority.

6. Conclusion

We conclude the results as follows:

(i) By carefully examining the coefficients of the principal components and key indicators, we find that the obtained quantitative values are not much different. This small difference shows that the digital transformation is achieved only if we pay attention to all extracted components. It also shows that all the influential factors in the implementation and realization of digital transformation can be considered as components of the whole ecosystem that are growing together to achieve the goal. Therefore, while analyzing each of the effective components, it is necessary to fully implement and properly exploit all the benefits of digital transformation, and the set of impact factors identified in a dynamic ecosystem should be examined.

(ii) Based on the results obtained and the review of recent crises, it is clearly stated that for the successful implementation and realization of digital transformation, it is necessary to pay attention to all components and align the indicators.

(iii) Based on the results, governance has the highest impact factor. However, in practice, not much attention has been paid to it. For example, in the field of regulation, infrastructure, policy-making, and the formulation of laws and regulations at the macro level, less has been paid. And we have never been able to create appropriate and consistent laws and regulations in line with technology and other operational indicators, and the main influential indicators in governance have always been raised later than other components. And, in the face of many technologies, we have seen that the alignment of the government with technology does not happen.

(iv) Examining the results, it was found that business models, along with governance, are very important. Extensive changes in the world in all aspects of life and in the economic sphere have led to the emergence of new business models, which in many cases there are severe structural differences from previous business models and in some cases new business models have been created that did not previously exist and have been created solely on the basis of new technology trends and tailored to new needs. In such circumstances, the domestic market of Iran is undergoing major changes: on the one hand, the relentless and increasing influx of new technologies and, on the other hand, the existence of traditional markets and old business models have caused some confusion. In such a situation, alignment of governance, business models, and technology are felt more and more. In other countries, in line with new technologies, new business models have been created, and in many areas, there are approved and sustainable business models. But the condition for successful implementation of digital transformation in domestic markets is to make a fundamental change in traditional business models and to create localized business models in line with emerging phenomena.

(v) In interviews with domestic experts and opinions extracted from experts in foreign conferences, the culture component is considered one of the vital and influential factors. The results of the research also showed that this component is in third place in terms of impact. A clear example in this area is social media. Social media has grown exponentially in recent years. In general, in the face of such phenomena, the spread and influence of which are beyond the control of societies, it is necessary to establish appropriate laws and regulations in the discussion of sovereignty, at the right time and with the nobility of all overt and covert visions.

(vi) Unfortunately, in our country, there are still no precise, specific, and complete regulations for using social media. And, in the most optimistic case, laws and regulations have occurred much later than the advent of technology. On the other hand, the main context of such phenomena generally occurs in societies that are very different from the cultural structure of our society. Therefore, in the face of the emergence and arrival of such phenomena, it is necessary to culturally harmonize and approve the laws and regulations of exploitation in appropriate conditions and time. In many cases, we have seen that the capabilities and possibilities of new social media are fundamentally different from the traditional infrastructure of our culture. Proper planning at the right time has created new problems as well as the spread of mistrust and lack of full use of social media.

(vii) Another example, in the field of culture, is the issue of dispersion and diversity of demographic classes in the country. A population of the community that has a higher average age is not easily able to use up-to-date and complete technologies. Most of these people are business owners and craftsmen who sometimes still follow traditional business models, or be ignored perhaps because of their inability to update information on the use of technologies and for cultural reasons. Therefore, while creating the necessary physical and cultural infrastructure, in changing new business models, this issue should be considered by the legislature. This part of the society, on the one hand, is important as an important economic sector and the owner of wealth and, on the other hand, as a customer of technology services, is of special importance. The level of literacy and awareness of up-to-date technology is very important in the successful realization and implementation of digital transformation.

(viii) One of the key necessities in digital transformation is related to a skilled and specialized workforce in this field. The statistics of the educated and university population in relation to the total population are acceptable. This part of society, as a customer and operator of technology, can more easily adapt to change. But, in order to implement and realize the digital transformation, the need for expert force in this field is very critical. The presence of people with related specialties and knowledge of the latest technologies in the world, along with strong scientific and technological centers, which are constantly active in the field of research and development, creates strong scientific support in updating and adapting to the conditions of society and the culture of the community. The digital transformation workforce must identify and meet the needs of society, update and localize existing technologies, and in terms of governance must act in such a way that we are not merely importers and users of technology. We need to play a more effective role in the research and development of technologies by increasing knowledge and collaborations.

What has been obtained from the results of research and analysis undoubtedly implies based on the high impact and continuity of all the studied components and should be considered in formulating the digital transformation plan strategy. Finally, successful and complete realization of digital transformation is only based on the emphasis and focus of all main components. Finally, as a suggestion for future research, the development of the model proposed in this research using other decision-making tools such as VIKOR and TOPSIS is proposed. Given that decision-making methods are highly dependent on the weights of the indicators, the use of integrated weight determination techniques such as BWM-entropy is recommended.

Data Availability

The data collected from the company are presented as a table in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Presenting a Multi-Echelon and Multi-Product Model for Inventory Control considering Shortages Using a Heuristic Algorithm

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In the present study, a mathematical model is provided for inventory management in a three-level supply chain including a supplier, a manufacturer, and a distributor, taking into account the potential for product deficiency. Significant parameters such as the optimal order size for raw materials, optimal production rate, optimal allowed deficiencies at each supply chain level, the of the vehicles and the number of times the products are delivered between the supply chain components have been provided aiming at minimizing inventory management costs in the supply chain. The problem was solved using a heuristic algorithm. The proposed model is implemented for 20 different numerical examples. According to the results, the difference between the solutions obtained from the algorithm and the solutions obtained from the optimal values with the real variables is an average of 1.52%.

1. Introduction

The integrated performance of suppliers, manufacturers, distributors, and customers, which make up the components of the supply chain, has been studied significantly during recent years [1–3]. From an operational perspective, supply chain management is to integrate the suppliers, manufacturers, warehouses, and storage centers in an effective manner, so that goods are produced and distributed in the right quantities, at the right time, and in the right place in a way that minimizes the cost of the entire system while maintaining a proper level of customer service [4, 5]. Thus, supply chain coordination is a plan that arranges the operations of supply chain members and enhances system benefits [6–8]. Inventory management problems are very significant in terms of minimization of the total cost of the chain and the cost of the final product [9]. The studies in this area have been so extensive that the search results on the Google Scholar led to 40300 results and on Scopus site, and it led to 2400 related articles [10, 11].

One of the first integrated models that has examined the inventory management for more than two members of the supply chain was provided by Banerjee and Kim [12] who analyzed the ordering of raw materials in the supply chain with one buyer, one manufacturer, and one supplier. This model was generalized by Lee [13] who analyzed and investigated ordering of raw materials in the supply chain, and, unlike the previous model, the author hypothesized that the manufacturer could place an order to the supplier several times its own economic output and could satisfy its demand while preparing multiple orders at different intervals. The Banerjee and Kim [12] model has also been reviewed by

Table 1: Literature review.

Authors	Multi-echelon	Multi-product	Inventory control	Heuristic algorithm	Shortage	Deficiency conditions
Safaei et al. [20]	*	*	*			
Shafipour-Omrani et al. [19]	*		*	*		
Olya et al. [18]			*	*		
Goodarzian et al. [16]			*	*		
Britt et al. [15]			*	*	*	
Banerjee et al. [14]		*	*			
Lee [13]	*	*				
This research	*	*	*	*	*	*

Banerjee et al. [14] in which the supply chain contains several buyers. The producer delivers once to each buyer at regular intervals so that they achieve the required inventory. Britt et al. [15] proposed a stochastic multi-objective model for master surgical scheduling and inventory problem. The intended uncertainty was considered as a scenario. They mainly targeted to maximize the utilization of the operating rooms and minimize the variance of weekly allocation of the surgeons. Genetic approaches and late acceptance hill climbing heuristics were employed for solving the model. Goodarzian et al. [16] developed a bi-objective network design considering route balancing, working time, and inventory problem. They considered two main aims including minimizing the total service time and total costs of HHC service. To solve their model, metaheuristic algorithms called social engineering optimization, firefly algorithm, and artificial bee colony were used and an improved social engineering optimization was developed. Yang et al. [17] presented a multi-objective mathematical model for inventory and scheduling problem. In the presented mathematical model, travel time and service time were taken as uncertain. Their main goal was to minimize the system costs and maximize the service level. The proposed mathematical model was solved using the improved multi-objective artificial bee colony and neighborhood search heuristic. The solution-derived results for the numerical instances indicated that the model performed appropriately. Olya et al. [18] proposed a stochastic mathematical model for resources management and inventory problem in the healthcare system, where the patient demand was uncertain and was satisfied using simulation. They pursued the goal to allocate the nurses to the patients and minimize the service costs. Deep learning and supervised and unsupervised methods were applied for solving the mathematical model. The results suggested that the multi-task learning solution approach operator outperformed other methods. Shafipour-Omrani et al. [19] presented inventory and transportation model for the LNG supply chain. The model minimizes the cost of sending natural gas from the primary port to the destination port. Considering the product variety and the way of presenting the constraint were the contributions of their paper. The results show that if the ships' capacity increases, the product variation decreases.

Safaei et al. [20] presented a new multi-period and multi-echelon mathematical model for closed-loop supply chain. They forecasted demand using time series model using autoregressive integrated moving average (ARIMA). Considering the cost of not satisfying the total amount of demand is the one the contributions of their paper.

Table 1 shows the literature review.

In the present paper, an inventory management model in a three-level supply chain is provided, which consists of a supplier, a manufacturer, and a distributor to determine the order size of raw material and optimal production, the capacity of vehicles, and the number of times the products are delivered between chain components in order to minimize the inventory size. The main objective of this research is minimizing the maintenance costs, inventory costs, and ordering and preparation costs. The research gaps are as follows:

(i) Ignoring three-level supply chain system taking into account the deficiency conditions.
(ii) Ignoring multi-echelon and multi-product model for inventory control in presented system.
(iii) Ignoring heuristic algorithm to solve the model.

The contributions of this paper are as follows:

(i) Considering three-level supply chain system taking into account the deficiency conditions.
(ii) Considering multi-echelon and multi-product model for inventory control in presented system.
(iii) Considering heuristic algorithm to solve the model.

Finally, a heuristic algorithm is used to determine the optimal solutions to the problem. In the following, the validity of the model and the proposed solution method are examined. In both cases, the results are satisfactory.

2. Modeling a Three-Level Supply Chain System Taking into Account the Deficiency Conditions

Indices:

i: manufacturer
r: raw material
f: distributor
s: production preparation
w: semi-finished products

Parameters:

P_i: manufacturer's i production rate

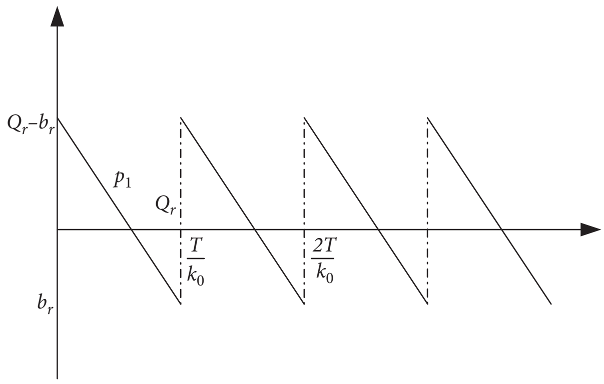

Figure 1: Inventory of raw materials.

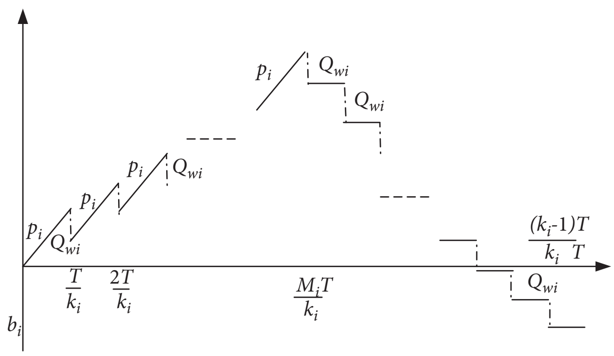

Figure 2: Inventory of manufacturer's products.

D: demand rate
H_r: cost of maintaining the inventory of raw material r for each product
H_{wi}: cost of maintaining each unit of semi-finished products w by the manufacturer i
H_f: cost of maintaining each unit of final product
π_r: cost of deficiency of each unit of raw material r
π_i cost of deficiency of each unit of goods for the manufacturer i
π_f: cost of deficiency of each unit of final product
A_r: cost of ordering raw material r
A_{si}: cost of production preparation s for the manufacturer i
A_{sf}: cost of production preparation s for the distributor f
A_{wi}: preparation costs for sending semi-finished products w to the manufacturer i
A_{wf}: preparation costs for sending semi-finished products w to the distributor f
A_f: preparation costs for sending final products to the final customers
I_t: inventory level at time t
I_{avg}: average inventory
T_{ui}: the time assigned at stage i for production in each production cycle
T_{di}: nonproductive time at stage i in each production cycle
TC_r: cost of maintaining raw material r
TC_r: cost of raw material r storage in the supplier
TC_{wi}: cost of maintaining products w in the manufacturer i
TC_f: cost of maintaining the final products in the distributor f
TC_{wi}: cost of maintaining semi-finished products w by the manufacturer i
TC_f: cost of maintaining the final products by the distributor f
TC: total supply chain costs

Variables:

Q: amount of products manufactured in each production cycle (optimal economic production rate)
Q_r: amount of raw material r that should be delivered from the supplier in each cycle
Q_{wi}: amount of products w in each delivery to the next step for the manufacturer i
Q_f: amount of final products in each delivery to the final customer
b_r: amount of ultimate deficiency for raw material r in the supplier
b_i: amount of ultimate deficiency in each production cycle in the manufacturer i
b_f: amount of ultimate deficiency of the final product in the distributor f
K_i: number of times the manufacturer's i products are sent in each production cycle
K_r: number of times to order delivery of raw material r in the supplier
m_i: number of times the products are sent at the time of manufacturing in each production cycle
K_f: number of times the final products are sent to customers in the distributor f
s: number of times the final products are sent to the final customers at the time of packaging in the distributor

2.1. Supplier Inventory Cost. At the supplier side, it is assumed that the demand rate for raw material inventory equals the rate of production of the manufacturer, i.e., P_1. Orders with a fixed size of Q_r are also sent to the raw material warehouse. The problem for this section to respond to the demand of the production station is to determine the order size of raw materials, number of orders in a production cycle, and the optimal deficiency. The inventory of raw materials is shown in Figure 1.

According to the above model and the costs of maintenance, ordering, and deficiency, the cost of raw materials is calculated as follows:

$$\mathrm{TC}_r = \left(\frac{D}{Q}\right)\left(A_r K_r + H_r I_{\mathrm{avg}} T_r + \pi_r b_{\mathrm{avg}} T_{br}\right). \qquad (1)$$

Since the average inventory in each production cycle and at the time of deficiency is equal to $I_{\mathrm{avg}} = Q_r - b_r/2$ and the average deficiency at the time of occurrence is equal to $\pi_{\mathrm{avg}} = b_r/2$ and considering the relevant time relations as $T_r = Q - k_r b_r/\mathrm{D}$ and $T_{br} = k_r b_r/\mathrm{D}$, by substituting the above relations, the cost of raw materials is determined as follows:

$$\mathrm{TC}_r = \frac{D}{Q} A_r K_r + H_r\left(\frac{Q_r - b_r}{2}\right)\left(\frac{Q - k_r b_r}{D}\right) + \pi_r \frac{k_r b_r^2}{2D}. \quad (2)$$

2.2. Inventory Cost of Manufacturer's Products. The products are produced by the manufacturer with the production rate p_i. Products on which the manufacturing process is performed are stored in the warehouse until they are sent to the manufacturer. Products are delivered from the manufacturer to the distributor in Q_{wi} packages by shipping equipment at the ordering times. The manufacturer's inventory level is presented in Figure 2.

In terms of the inventory of semi-finished products in the manufacturer, the following relations are given:

$$T_{wi} = \frac{m_i T}{k_i}. \quad (3)$$

The number of products on which the manufacturing process is performed in station i and in each production, cycle is equal to the amount of economic production Q, which shows the following relation:

$$\begin{aligned} Q &= \int_0^{T_{wi}} P_i \mathrm{d}t, \\ &= P_i T_{wi}, \\ &= P_i \frac{m_i T}{k_i}. \end{aligned} \quad (4)$$

The average amount of products made in the manufacturer is calculated as follows:

$$\begin{aligned} I_{\mathrm{avg}} &= \frac{1}{2}\left(Q_{wi}\left(k_i - m_i + 1\right) - b_i\right), \\ \pi_{\mathrm{avg}} &= \frac{1}{2} b_i. \end{aligned} \quad (5)$$

Therefore, the inventory cost for the manufacturer's products is calculated as follows:

$$\begin{aligned} \mathrm{TC}_{wi} &= \frac{D}{Q}\left(A_{si} + A_{wi}k_i + H_{wi}\frac{\left(Q_{wi}\left(k_i - m_i + 1\right) - b_i\right)}{2}\frac{\left(Q_{wi}\left(k_i - m_i + 1\right) - b_i\right)}{D} + \pi_i \frac{b_i}{2}\frac{b_i}{D}\right) \longrightarrow \mathrm{TC}_{wi}, \\ &= \frac{D}{Q}\left(A_{si} + A_{wi}k_i + H_{wi}\frac{\left(Q_{wi}\left(k_i - m_i + 1\right) - b_i\right)^2}{2D} + \pi_i \frac{b_i^2}{2D}\right) \end{aligned} \quad (6)$$

2.3. Inventory Cost of Distributor Products. It is assumed that the preparation rate of the final products in the distributor increases with p_f rate. The manufactured products are delivered to end customers in the same sizes. The average inventory of final products in each production cycle is calculated as follows:

$$I_{\mathrm{avg}} = \frac{1}{2}\left(Q_f\left(k_f - m_f + 1\right) - b_f\right). \quad (7)$$

The total cost of inventory of final products is obtained as follows:

$$\begin{aligned} \mathrm{TC}_f &= \frac{D}{Q}\left(A_{s(N+1)} + A_f k_f + H_f \frac{\left(Q_f\left(k_f - s + 1\right) - b_f\right)}{2}\frac{\left(Q_f\left(k_f - s + 1\right) - b_f\right)}{D} + \pi_f \frac{b_f}{2}\frac{b_f}{D}\right) \longrightarrow \mathrm{TC}_f, \\ &= \frac{D}{Q}\left(A_{s(N+1)} + A_f k_f + H_f \frac{\left(Q_f\left(k_f - s + 1\right) - b_f\right)^2}{2D} + \pi_f \frac{b_f^2}{2D}\right). \end{aligned} \quad (8)$$

Limitations of the Problem. In order not to face a deficiency in semi-finished products in the manufacturer, conditions should be established where the level of deficiency in the manufacturer is less than the allowable deficiency in the distributor. Therefore, the following conditions must be considered in the problem.

$$\begin{aligned} &\text{if} \quad b_i \le b_f \longrightarrow b_f = b_f, \\ &\text{if} \quad b_f \le b_i \longrightarrow b_f = b_i. \end{aligned} \quad (9)$$

To linearize the above constraints in the problem, it is sufficient to define these equations in a linear manner by defining the binary variable $y \in (0, 1)$ as follows:

$$b_f + M(1-y) \geq b_i,$$
$$b_f - \text{My} \leq b_i, \quad (10)$$
$$b_f = b_f y + b_i (1-y).$$

The total cost of a three-level supply chain is as follows. The total cost of the supply chain is calculated as follows by the sum of the costs related to the inventory of the supplier, manufacturer, and distributor.

$$\text{TC}_m = \text{TC}_r + \text{TC}_{wi} + \text{TC}_f. \quad (11)$$

So, we have

$$\text{TC}_m = \frac{D}{Q}A_r K_r + H_r\left(\frac{Q_r - b_r}{2}\right)\left(\frac{Q - k_r b_r}{Q}\right) + \pi_r \frac{k_r b_r^{\,2}}{2Q}$$
$$+\left(\frac{D}{Q}A_{si} + \frac{D}{Q}A_{wi}k_i + H_{wi}\frac{(Q_{wi}(k_i - m_i + 1) - b_i)^2}{2Q} + \pi_i \frac{b_i^{\,2}}{2Q}\right),$$
$$+\left(\frac{D}{Q}A_{sf} + \frac{D}{Q}A_{wf}k_f + H_f\frac{\left(Q_f\left(k_f - s + 1\right) - b_f\right)^2}{2Q} + \pi_f \frac{b_f^{\,2}}{2Q}\right). \quad (12)$$

The size and number of transferred units in each station are related to the amount of economic production of the supply chain, i.e., according to the following relationships.

$$Q = k_r Q_r$$
$$= k_i Q_{wi} \quad (13)$$
$$= k_f Q_f.$$

By substituting the cost of inventory in the relevant equations, the cost of inventory in the entire supply chain will be determined as follows:

$$\text{TC}_m = \frac{D}{Q}A_r K_r + H_r\left(\frac{Q/k_r - b_r}{2}\right)\left(\frac{Q - k_r b_r}{Q}\right) + \pi_r \frac{k_r b_r^{\,2}}{2Q}$$
$$+\left(\frac{D}{Q}A_{si} + \frac{D}{Q}A_{wi}k_i + H_{wi}\frac{(Q/k_i(k_i - m_i + 1) - b_i)^2}{2Q} + \pi_i \frac{b_i^{2}}{2Q}\right),$$
$$+\left(\frac{D}{Q}A_{sf} + \frac{D}{Q}A_{wf}k_f + H_f\frac{\left(Q/k_r\left(k_f - m_f + 1\right) - b_f\right)^2}{2Q} + \pi_f \frac{b_f^{\,2}}{2Q}\right), \quad (14)$$

subject to

$$b_f + M(1-y) \geq b_i, \quad (15)$$

$$b_f - \text{My} \leq b_i, \quad (16)$$

$$b_f = b_f y + b_i(1-y), \quad (17)$$

$$k_i, k_r, k_f \in \text{int}, \quad (18)$$

$$Q, b_i, b_r, b_f, \in \text{real}, \quad (19)$$

$$y \in (0, 1). \quad (20)$$

Of course, it should be noted that in this problem, the variables k_i, k_r, and k_f, i.e., the number of times the materials and products are delivered, are integer variables.

3. Solution Algorithm

Step 1. Determination of the optimal solutions of the three-level supply chain with real variables.

The optimal values of deficiency variables in different stations are determined as follows as the first step:

$$\frac{\partial \text{TC}_m}{\partial b_r} = -\frac{H_r}{2Q}\left(Q - k_r b_r + Q - k_r b_r\right) + \frac{\pi_r}{2Q} 2k_r b_r,$$
$$= 0 \longrightarrow 2k_r b_r \pi_r,$$
$$= 2H_r\left(Q - k_r b_r\right) \longrightarrow b_r^*,$$
$$= \frac{Q}{k_r\left(\pi_r/H_r + 1\right)},$$
$$\frac{\partial \text{TC}_m}{\partial b_i} = -\frac{2\pi_i b_i}{2Q} - \frac{2H_{wi}\left(Q\left(1 + \text{D}/P_i + 1/k_i\right) - b_i\right)}{2Q},$$
$$= 0 \longrightarrow b_i\left(\pi_i + H_{wi}\right)$$
$$= H_{wi}\left(Q\left(1 - \frac{D}{P_i} + \frac{1}{k_i}\right) - b_i\right) \longrightarrow b_i^* \quad (21)$$
$$= \frac{H_{wi}Q\left(1 - D/P_i + 1/k_i\right)}{\pi_i + 2H_{wi}},$$
$$\frac{\partial T\ C_m}{\partial b_f} = -\frac{2\pi_f b_f}{2Q} - \frac{2H_f\left(Q\left(1 - D/P_f + 1/k_f\right) - b_f\right)}{2Q},$$
$$= 0 \longrightarrow b_f\left(\pi_f + H_f\right)$$
$$= H_f\left(Q\left(1 - \frac{D}{P_f} + \frac{1}{k_f}\right) - b_f\right) \longrightarrow b_f^*,$$
$$= \max\left(\frac{H_f\left(2 - D/P_f + 1/k_f\right)Q}{2\left(\pi_f + H_f\right)}, b_i^*\right).$$

By substituting the optimal deficiencies calculated in the objective function of the problem and simplification of the objective function, we have

$$\mathrm{TC}_m = \frac{D}{Q}A_r K_r + H_r\left(\frac{Q/k_r - Q/k_r\left(1/\left(1+\pi_r/H_r\right)\right)}{2}\right)\left(\frac{Q - k_r Q/k_r\left(1/\left(1+\pi_r/H_r\right)\right)}{Q}\right) + \pi_r\frac{k_r Q^2/k_r^2\left(1/\left(1+\pi_r/H_r\right)\right)^2}{2Q}$$
$$+\frac{D}{Q}A_{si} + \frac{D}{Q}A_{wi}k_i + \frac{H_{wi}Q}{2}\left(\left(1-\frac{D}{P_i}+\frac{1}{k_i}\right)\left(\frac{\pi_i + H_{wi}}{\pi_i + 2H_{wi}}\right)\right)^2 + \frac{\pi_i Q}{2}\left(\left(1-\frac{D}{P_i}+\frac{1}{k_i}\right)\frac{H_{wi}}{\pi_i + 2H_{wi}}\right)^2$$
$$+\frac{D}{Q}A_{sf} + \frac{D}{Q}A_{wf}k_f + \frac{H_f Q}{2}\left(\left(1-\frac{D}{P_f}+\frac{1}{k_f}\right)\left(\frac{\pi_f + H_f}{\pi_f + 2H_f}\right)\right)^2 + \frac{\pi_f Q}{2}\left(\left(1-\frac{D}{P_f}+\frac{1}{k_f}\right)\frac{H_f}{\pi_f + 2H_f}\right)^2$$
$$\longrightarrow \mathrm{TC}_m = \frac{D}{Q}A_r K_r + \frac{H_r Q}{2k_r}\left(\frac{\pi_r}{H_r+\pi_r}\right)^2 + \frac{\pi_r Q}{2k_r}\left(\frac{H_r}{H_r+\pi_r}\right)^2$$
$$+\frac{D}{Q}A_{si} + \frac{D}{Q}A_{wi}k_i + \frac{H_{wi}Q}{2}\left(\left(1-\frac{D}{P_i}+\frac{1}{k_i}\right)\left(\frac{\pi_i + H_{wi}}{\pi_i + 2H_{wi}}\right)\right)^2 + \frac{\pi_i Q}{2}\left(\left(1-\frac{D}{P_i}+\frac{1}{k_i}\right)\frac{H_{wi}}{\pi_i + 2H_{wi}}\right)^2$$
$$+\frac{D}{Q}A_{sf} + \frac{D}{Q}A_{wf}k_f + \frac{H_f Q}{2}\left(\left(1-\frac{D}{P_f}+\frac{1}{k_f}\right)\left(\frac{\pi_f + H_f}{\pi_f + 2H_f}\right)\right)^2 + \frac{\pi_f Q}{2}\left(\left(1-\frac{D}{P_f}+\frac{1}{k_f}\right)\frac{H_f}{\pi_f + 2H_f}\right)^2. \tag{22}$$

At this step, we must determine the optimal problem variables using the partial derivatives of the objective function relative to the problem variables as follows:

$$\begin{aligned}
&\frac{\partial \mathrm{TC}_m}{\partial K_r} = 0 \longrightarrow K_r^*,\\
&= \sqrt{\frac{H_r\pi_r}{2\mathrm{DA}_r\left(H_r+\pi_r\right)}Q},\\
&\frac{\partial \mathrm{TC}_m}{\partial K_i} = 0 \longrightarrow k_i^*,\\
&= \sqrt{\frac{H_{wi}\left(\pi_i + H_{wi}/\pi_i + 2H_{wi}\right)^2 + \pi_i\left(H_{wi}/\pi_i + 2H_{wi}\right)^2}{2\mathrm{DA}_{wi}}Q},\\
&\frac{\partial \mathrm{TC}_m}{\partial K_f} = \frac{D}{Q}A_{wf} - \frac{Q}{2k_f^2}\left(H_f\left(\frac{\pi_f+H_f}{\pi_f+2H_f}\right)^2 + \pi_f\left(\frac{H_f}{\pi_f+2H_f}\right)^2\right) = 0,\\
&k_f^* = \sqrt{\frac{H_f\left(\pi_f + H_f/\pi_f + 2H_f\right)^2 + \pi_f\left(H_f/\pi_f + 2H_f\right)^2}{2\mathrm{DA}_{wf}}Q}.
\end{aligned} \tag{23}$$

Table 2: The input parameters of a three-level supply chain.

D	P_1	P_2	H_r	H_{wi}	H_f	π_r	π_i	π_f	A_r	A_{si}	A_{wi}	A_{wf}	A_{sf}
36000	42000	45000	400	500	700	2000	1000	800	400	1300	350	300	1250

Table 3: Solution result.

Q	Q_r	Q_{wi}	Q_f	b_r	b_i	b_f	K_i	K_r	K_f	TC
22161	7387	4432	3693	1622	1899	2585	3	5	6	3128606

As observed, the optimal number of orders at different levels is determined based on a function of the amount of economic production. In this section, by obtaining the optimal economic production using the partial derivative of the objective function relative to Q, the optimal value of all problem variables will be determined using the above relations. So, we have

$$
\begin{aligned}
\frac{\partial \mathrm{TC}_m}{\partial Q} &= -\frac{D}{Q^2}A_rK_r + \frac{1}{2k_r}\left(\frac{H_r\pi_r}{H_r+\pi_r}\right) \\
&\quad -\frac{D}{Q^2}A_{si} - \frac{D}{Q^2}A_{wi}k_i + \frac{(1-D/P_i+1/k_i)}{2}\left(H_{wi}\left(\frac{\pi_i+H_{wi}}{\pi_i+2H_{wi}}\right)^2 + \pi_i\left(\frac{H_{wi}}{\pi_i+2H_{wi}}\right)^2\right) - \frac{D}{Q^2}A_{si} - \frac{D}{Q^2}A_{wi}k_i \\
&\quad + \frac{(1-D/P_f+1/k_f)}{2}\left(H_f\left(\frac{\pi_f+H_f}{\pi_f+2H_f}\right)^2 + \pi_f\left(\frac{H_f}{\pi_f+2H_f}\right)^2\right) \longrightarrow \\
&\quad \frac{D}{Q^2}\left(A_rK_r + A_{si} + A_{wi}k_i + A_{sf} + A_{wf}k_f\right) \\
&= \frac{1}{2k_r}\left(\frac{H_r\pi_r}{H_r+\pi_r}\right) + \frac{(1-D/P_i+1/k_i)}{2}\left(H_{wi}\left(\frac{\pi_i+H_{wi}}{\pi_i+2H_{wi}}\right)^2 + \pi_i\left(\frac{H_{wi}}{\pi_i+2H_{wi}}\right)^2\right), \\
&\quad + \frac{(1-D/P_i+1/k_i)}{2}\left(H_f\left(\frac{\pi_f+H_f}{\pi_f+2H_f}\right)^2 + \pi_f\left(\frac{H_f}{\pi_f+2H_f}\right)^2\right) \longrightarrow \\
Q^* &= \sqrt{\frac{D\left(A_rK_r + A_{si} + A_{wi}k_i + A_{sf} + A_{wf}k_f\right)}{1/2k_r\left(H_r\pi_r/H_r+\pi_r\right) + (1-\mathrm{D}/P_i+1/k_i)/2\left(H_{wi}\left(\pi_i+H_{wi}/\pi_i+2H_{wi}\right)^2 + \pi_i\left(H_{wi}/\pi_i+2H_{wi}\right)^2\right) + \left(1-D/P_f+1/k_f\right)/2\left(H_f\left(\pi_f+H_f/\pi_f+2H_f\right)^2 + \pi_f\left(H_f/\pi_f+2H_f\right)^2\right)}}, \\
Q^* &= \frac{2D\left(A_{si}+A_{sf}\right)}{\sqrt{\left(1-D/P_f\right)\left(H_{wi}\left(\pi_i+H_{wi}/\pi_i+2H_{wi}\right)^2 + \pi_i\left(H_{wi}/\pi_i+2H_{wi}\right)^2\right) + \left(1-D/P_f\right)\left(H_f\left(\pi_f+H_f/\pi_f+2H_f\right)^2 + \pi_f\left(H_f/\pi_f+2H_f\right)^2\right)}}.
\end{aligned}
\tag{24}
$$

With the replacement of K_i^*, K_f^*, and K_r^* in the above equation and after calculation and simplification, the optimal value of Q variable will be obtained as follows:

$$
Q^* = \frac{2D\left(A_{si}+A_{sf}\right)}{\sqrt{\left(1-D/P_i\right)\left(H_{wi}\left(\pi_i+H_{wi}/\pi_i+2H_{wi}\right)^2 + \pi_i\left(H_{wi}/\pi_i+2H_{wi}\right)^2\right) + \left(1-D/P_f\right)\left(H_f\left(\pi_f+H_f/\pi_f+2H_f\right)^2 + \pi_f\left(H_f/\pi_f+2H_f\right)^2\right)}}.
\tag{25}
$$

After determining the optimal economic production according to (25) and substituting the value obtained in (15)–(20), the optimal real values of the other problem variables and the optimal real value of the objective function

Table 4: Efficiency of the proposed heuristic method.

Problem	Z = optimal real value of the problem	TC = optimal integer value of the problem	% = percentage difference between the optimal real solution and optimal integer solution to the problem (%)
1	244301.3	245867.2	0.64
2	246162.7	244085.6	0.84
3	248188.5	246202.6	0.80
4	247622.5	255067.1	3.01
5	277597.1	279114.3	0.55
6	281391	281906.4	0.18
7	282395.6	285566.8	1.12
8	281966	289377	2.63
9	281116.2	290394.9	3.30
10	306972.5	314815.5	2.55
11	307402.1	316513.7	2.96
12	206642.8	205731.3	0.44
13	209231.6	210423	0.57
14	211189.3	210961.8	0.11
15	213020.4	215275	1.06
16	212720.8	218395	2.67
17	223065.9	228946.5	2.64
18	245184.9	241843.7	1.36
19	258218	256284.7	0.75
20	262500	268350.2	2.23
Average			1.52

of the problem are determined.

$$b_r^* = \frac{Q^*}{k_r(\pi_r/H_r+1)},$$

$$b_i^* = \frac{H_{wi}(1-D/P_i+1/k_i)}{\pi_i+2H_{wi}}Q^*,$$

$$b_f^* = \max\left(\frac{H_f(2-D/P_f+1/k_f)Q}{2(\pi_f+H_f)}, b_i^*\right),$$

$$K_r^* = \sqrt{\frac{H_r\pi_r}{2\mathrm{DA}_r(H_r+\pi_r)}}Q^*,$$

$$k_i^* = \sqrt{\frac{H_{wi}(\pi_i+H_i/\pi_{wi}+2H_{wi})^2+\pi_i(H_i/\pi_{wi}+2H_{wi})^2}{2\mathrm{DA}_{wi}}}Q^*,$$

$$k_i^* = \sqrt{\frac{H_{wi}(\pi_i+H_i/\pi_{wi}+2H_{wi})^2+\pi_i(H_i/\pi_{wi}+2H_{wi})^2}{2\mathrm{DA}_{wi}}}Q^*,$$

$$k_f^* = \sqrt{\frac{H_f(\pi_f+H_f/\pi_f+2H_f)^2+\pi_f(H_f/\pi_f+2H_f)^2}{2\mathrm{DA}_{wf}}}Q^*. \tag{26}$$

Step 2. Method of determining the optimal integer solution of the problem.

Step 3. Method of determining the variable.

In this case, too, the concepts of high and low-bound false cost method have been used to determine the variable in each stage. Therefore, at each decision-making level to determine the variable on which branching should be performed, first the increase or decrease level of the objective function is determined for all remaining variables in case branching is performed on the variable in each of the following problems. Then, a variable is selected for branching that has the maximum average difference between the values of the objective function in the two branches at all stages.

Step 4. Assigning the probability of selection to the decision variables in each step.

In order to use all the data generated at all different levels in the decision tree, the probability of selecting each variable is calculated as follows.

The probability of selecting variable i in each step = $\mathrm{AVG}|\mathrm{costup}_i - \mathrm{costdown}_i|/\sum_i \mathrm{AVG}|\mathrm{costup}_i - \mathrm{costdown}_i|$.

According to the assigned probability, in each stage, a variable will be selected that has the average maximum difference between the costs of the lower and upper branches up to that stage.

Step 5. Determining the value of selected variable.

After determining the desired variable in the step, a value is considered for the variable that induces the least increase in the objective function.

Example 1. The input parameters of a three-level supply chain are shown in Table 2.

Modeling and solving the model using the proposed method based on the branch and bound algorithm, the resulting solutions to the problem are determined as shown in Table 3.

4. Efficiency of the Proposed Heuristic Method

The proposed model is implemented for 20 different numerical examples. In Table 4, the efficiency of the method used is shown in comparison with the real optimal values.

According to the results, the difference between the solutions obtained from the algorithm and the solutions obtained from the optimal values with the real variables is an average of 1.52%.

5. Managerial Insights

The proposed model can be used for products with high maintenance costs or those subject to special conditions, including chemical and hazardous products, sensitive electronic and telecommunication products, and perishable products. As there was no official database for some parts of cost, the experts' estimations were sought to help. The questions about the inventory costs for each route have been categorized and the estimated costs have been entered into the mathematical model. The model is presented as a separate run, which paves the ground for the simulation to be run several times and to report the average of the obtained results. This minimizes simulation errors as much as possible.

6. Conclusion

In this paper, first, the proposed mathematical models related to the application of inventory control system in three-level supply chains were investigated, and then, an inventory management model was presented considering the conditions of deficiency. Since the model provided is in a mixed nonlinear programming form, the branch and bound algorithm is used to determine the solutions to the problem.

The results are as follows:

(i) According to the results, the difference between the solutions obtained from the algorithm and the solutions obtained from the optimal values with the real variables is an average of 1.52%.

(ii) According to the assigned probability, in each stage, a variable will be selected that has the average maximum difference between the costs of the lower and upper branches up to that stage.

To evaluate the efficiency of the proposed model, examples for different supply chains were examined and the values of the objective function obtained using the branch and bound algorithm were measured with the optimal real values of the objective function, which indicates the appropriate efficiency of the algorithm. To expand the proposed problem, any of the following conditions can be considered in this problem:

(i) Taking into account the possible conditions in relation to parameters such as delivery, production, loading, and unloading times.

(ii) Expanding the models offered in multi-product mode and considering the relationships and limitations between different products.

(iii) Limiting the number of orders and transfers of products between different stations.

(iv) Considering limitations such as storage space, amount of capital, and so on in the problem.

(v) Considering specific conditions for demand, such as the dependence of demand on price and inventory, and considering advertising-related activities to increase final demand.

(vi) Considering more than one member at each level of the supply chain.

(vii) Considering cooperation agreements between supply chain components.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Evaluating the Performance of Emergency Centers during Coronavirus Epidemic Using Multi-Criteria Decision-Making Methods (Case Study: Sari City)

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In this study, due to the importance of emergency centers and patient transport vehicles in epidemic conditions, the performance of emergency centers has been evaluated based on health protocols. The criteria were first divided into preventive and operational sections by collecting opinions, health experts, standard criteria, and the Delphi method. Preventive criteria for evaluating emergency centers and operating criteria for assessing vehicles in these centers are considered. The weighting of the determined criteria was done by the triangular fuzzy aggregation method. According to the standard criteria, the emergency centers have been evaluated for a 30-day period. The results have been assessed as a qualitative and quantitative matrix using the PROMETHEE method. The results showed better performance of Center A (63%) due to proper performance and better compliance with protocols in both criteria (preventive and operational). The reason for the superiority of this center over Center B can be considered the better performance of this center in terms of prevention indicators and better performance of the center's vehicles (Ambulance A-1 and Ambulance A-2) in the performance index by observing the standards.

1. Introduction

In late 2019, a disease emerged in Wuhan, China, with symptoms similar to pneumonia and acute respiratory illness [1]. After a few months, it became a global epidemic [2]. This virus is known as the acute coronavirus syndrome (SARS-CoV-2) or COVID-19 because it belongs to the large family of coronavirus [3]. The World Health Organization has issued guidelines to prevent the spread of COVID-19 as much as possible, such as banning unnecessary travel, closing public and busy centers, quarantine, social distance, and use of personal protective equipment (PPE) [4]. The virus has challenged public health [5]. So far, more than 1.6 million people have lost their lives, a significant number of whom are health workers [6]. Due to the COVID-19 epidemic, much pressure was put on health workers, the first of which was high work pressure and psychological factors [7, 8]. The second was employees' pressure to get the virus due to a lack of personal protective equipment (PPE). In some cases, asymptomatic people have been found to carry the COVID-19 [9]. Therefore, it makes it harder to fight the disease, affecting the health of a community, health workers, and even the families of health workers [10]. Hospitals are among the most sensitive centers against COVID-19; weaknesses such as lack of facilities in these centers cause more pressure on the whole community. As a result, the number of patients and deaths of this disease increases dramatically [11]. The emergency department (ED) has delinquent equipment such as patient transport vehicles, various separate rooms such as isolated rooms, pre-rooms, equipment, and facilities for patients' care and treatment, and having knowledgeable and sufficient staff [12]. In the COVID-19 epidemic, it is essential to have well-equipped patient transport vehicles separate from other patients [13]. Ambulance crews, such as isolation ward staff, should be in good mental condition and have adequate equipment (such as PPE) and equipment needed for patients [14]. In the next step, this is the emergency department of each hospital, responsible for patient care and maintenance. The emergency department's other important and main task is to save patients' lives in other wards and protect staff's lives [15]. Due to this virus's unpredictability, which causes delinquent symptoms and problems in delinquent individuals due to their age and immune system status, having adequate equipment and staff with sufficient information can be a good way to reduce COVID-19 be disease mortality [4]. The COVID-19 pandemic occurred suddenly and unexpectedly in many countries [16]. The evolution of COVID-19 and the unpredictability of the virus and the inconsistencies of health systems worldwide have made it difficult to combat the epidemic and achieve safety [17, 18]. This epidemic has challenged public health [19]. The virus was initially thought to be transmitted only through people with certain symptoms. Still, with continuous transmission of the disease by asymptomatic people who carry the virus, the constant presence of health workers in the emergency departments is mandatory. Because this constant presence means that the emergency department staff is always close to the person with COVID-19, it increases the risk of staff contracting the disease, causing the disease to become more prevalent and even endangering staff families, so about 50% of emergency department staff have symptoms such as depression, fear, and anxiety about expressing themselves, and research shows that about 10%–20% of people with COVID-19 are health workers, especially in the emergency department (ICU) [20–23]. Given these points, the continued use of personal protective equipment (PPE) is essential for both health workers and the general public to reduce this disease's incidence. Still, excessive use of PPE by the community has reduced the PPE standard available to health workers [24]. Due to the importance of emergency centers and patient transport vehicles in epidemic conditions and due to the increase in virus transmission rate among emergency personnel and patients compared with normal conditions, in this study, the evaluation of the performance of emergency centers during the epidemic has been considered. Given the importance of the research topic, the answer to the question of whether the emergency centers (emergency centers considered in the study area) have adapted to the epidemic conditions? Do they function well during an epidemic? To answer this question, in this research, two emergency centers in Sari will be examined in terms of preventive and operational criteria. In this study, considering the essential role that emergency department equipment plays in the fight against this disease, to use multicriteria decision-making methods, evaluates the performance of emergencies and patient transport vehicles according to compliance with health protocol times. The rest of the study is organized as follows: the literature review will be explained in the second section. In the third section, the research method will be described. In this section, the weighting methods of the criteria and their results will be given. In the fourth and fifth sections, sampling methods and the results of these evaluations will be explained. The discussion section is presented in the sixth section. Finally, the conclusion will be stated in the seventh section.

2. Literature Review

With the introduction of COVID-19 in China and its spread to all continents of the world, much research has been done on various aspects of the virus. Zhu et al. [25] evaluated and prioritized patients whose treatment was delayed for any reason; this study is multicriteria decision-making (MCDM) problem. They used two methods DEMATEL and VIKOR because both quantitative and qualitative criteria are included in the study. Both ways showed their efficiency. Spoorthy et al. [26] examined the mental health problems of healthcare workers during the epidemic. Factors such as age, insomnia, occupation, and increased stress are related to employees' mental health. Ng et al. [27] demonstrated the importance of health workers using personal protective equipment (PPE) during the COVID-19 epidemic. Employees who were two meters or less away from patients are considered at high risk of this disease. Nguyen et al. [28] who given the importance of using (PPE) by health workers and who are at the forefront of the fight against COVID-19 to the general public determined the needs. The results showed that the healthcare system and providing sufficient resources for PPE should also hire more staff. Amin [29] using 250 questionnaires distributed among health workers and physicians examined the psychological effects of COVID-19 in the community. According to the results, the more people are aware of COVID-19 and the criteria for its psychological effects, and the more its psychological effects will be reduced. Jahantigh and Ostovare [30] using the organizational preferential ranking method and PROMETHHE II examined 47 influential factors to evaluate teaching hospital sections' performance; this evaluation was performed on teaching hospitals in Tehran, Iran. The results show that a significant number of teaching hospitals are inefficient. Liao et al. [31] by creating a framework of aggregation method based on normalization solved the screening problem, obtained critical screening factors from the fuzzy Delphi method, and analyzed the proposed method. Choukolaei et al. [32] by determining 25 quantitative-qualitative criteria by experts by the Delphi method evaluated isolation room and anteroom of coronavirus hospitals in Sari. They prioritized the options using the fuzzy method. SWARA-PROMETHEE is used. Yucesan and Gul [33] reviewed and prioritized hospitals in terms of services provided, using fuzzy AHP and fuzzy TOPSIS, and they presented this study. The hospitals in question are located in Turkey, and the results, while showing the effectiveness of these two methods, also identified the top hospitals. Kriksciuniene and Sakalauskas [34] ranked hospitals based on the number of beds, patients, and cost. Their ranking method was the regression method and compared with each other using an analytic hierarchy process.

In this study, due to the importance of emergency health personnel and ambulance personnel using PPE during the COVID-19 epidemic and reducing health workers' mortality and maintaining their mental health, the emergency services are performed according to the use of PPE. To obtain the criteria and subcriteria, the fuzzy Delphi method is used in which experts have been used to evaluate these centers. For weighting and determining the questionnaire according to the criteria, the triangular fuzzy aggregation method was divided into preventive factors. Operating characteristics were determined using Morgan's table sampling and field research. Finally, the emergencies were ranked through the PROMETHEE method. Lotfi et al. [35] have developed a robust regression-based optimization (RO) approach to effectively predict the number of patients with recently confirmed coronavirus infection (COVID-19). The mean and average of the uncertain parameters have been calculated using the conditional value at risk (CVaR). Sensitivity was examined. Finally, their proposed model had the lowest mean absolute deviation (MAD) and the highest correlation coefficient compared with other models.

Lotfi et al. [36] to improve the inventory management system and deal with uncertainty and disruption in COVID-19 conditions proposed three models of resilience and sustainable healthcare supply chain (RSHCSC) using strong fuzzy and data-driven optimization with a random planning approach. The mean and average of the uncertain parameters have been calculated using the conditional value at risk (CVaR). The results show that increasing the fuzzy shear, confidence level, robustness coefficient, flexibility coefficient, and CVaR confidence level increase the cost.

Modibbo et al. [37] by presenting a mixed-integer linear programming model using a multicriteria decision-making process, the best qualified suppliers in the pharmaceutical industry are examined and a model for supplier selection problems is proposed. They reduce the size of the data from the concept of analysis. They also used the principal component analysis (PCA). They also tested the concept of triangular fuzzy number (TFN) on the reliability of decision-makers (DMs).

Navaei et al. [38] by presenting a multi-cycle and multiproduct model for hospital evacuation and drug supply chain for critical patients and considering the Epsilon constraint method compared and evaluated the performance of solution methods.

Moreira et al. [39] to predict and identify infected patients in epidemic conditions analyzed machine learning algorithms. They analyzed and evaluated the options using the PROMETHEE-GAIA method. Finally, they made a clear analysis of the selection of pre-algorithms. Nose was introduced to fight COVID-19.

Martins et al. [40] using three multicriteria decision-making techniques evaluated the main preventive measures in COVID-19 administrative services. They used PROMETHEE I, PROMETHEE II, and ELECTRE III techniques to prioritize preventive measures. Analysis of the results shows that the use of masks, gel alcohol along with physio-social distance and training were the most effective ways to prevent the outbreak of COVID-19. The literature review table is as follows (Table 1):

The research contribution is as follows:

(i) Using the Delphi method to collect and classify criteria and using the TFN-PROMETHEE technique to evaluate options during epidemic

(ii) Applying preventive and operational criteria to assess emergencies during an epidemic

(iii) Considering preventive and operational criteria simultaneously

This study aimed to evaluate the performance of emergency services in Sari, Iran, following health protocols' observance.

3. Research Methodology

The information required for this study was collected through the library, documentary, previous studies, and field studies. It was identified and selected with health experts' cooperation and the Delphi method subcriteria and the criteria. The experts then weighed these criteria using the triangular fuzzy aggregation method. A questionnaire including operational and preventive questions consisted of ten questions, and the importance of each criterion was prepared. Using Morgan's table and considering each emergency's average daily operations, the number of samples from the patient car's missions was 52 samples per day. The vehicles carrying each emergency station (each containing two vehicles) were evaluated in a month by daily sampling. The average performance of each of these indicators and the quality evaluation questionnaire of these databases are considered as input information. Finally, the performance of each emergency center was evaluated using the PROMETHEE method. Figure 1 shows an overview of the research.

The advantages of the methods used in this research are as follows:

(i) *Delphi Method*: The Delphi method uses a questionnaire to collect ideas by creating coordination between the expert opinions. Delphi is referred to as an integrated method, that is, a combination of qualitative and quantitative methods [41, 42]. The Delphi method is based on the logical assumption that several thoughts are better than one thought [43]. In the Delphi method, the questionnaire is performed in

Table 1: Literature review.

No.	Author	Evaluating the performance	COVID-19 case	Delphi method	Preventive and operational criteria	Uncertainty
1	Martins et al. [40]	*				
2	Moreira et al. [39]	*	*			
3	Navaei et al. [38]	*				*
4	Modibbo et al. [37]	*				*
5	Lotfi et al. [36]	*	*			
6	Lotfi et al. [35]	*	*			
7	Kriksciuniene and Sakalauskas [34]	*		*		
8	Yucesan and Gul [33]				*	*
9	Choukolaei et al. [32]	*		*		
10	Liao et al. [31]	*				*
11	Jahantigh and Ostovare [30]	*			*	
12	Amin [29]	*	*			
13	Nguyen et al. [28]	*	*			
15	**This study**	*	*	*	*	*

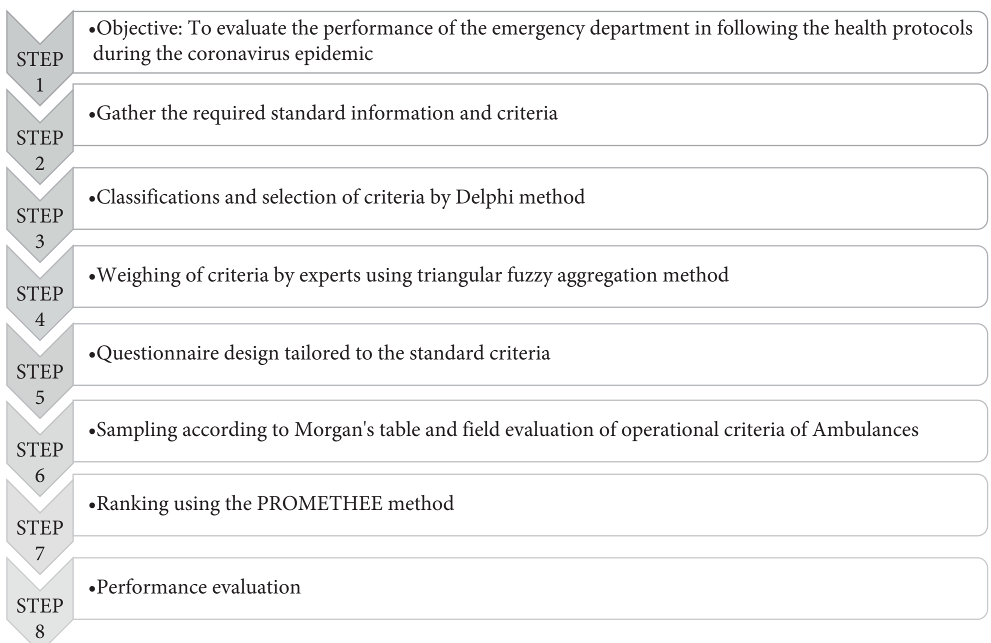

Figure 1: Overview of the research.

two or more stages and the results obtained from the previous courses are used for the new period of compiling and modifying the questionnaire.

(ii) *Triangular Fuzzy Aggregation*: the traditional process of quantifying people's perspectives does not fully reflect the human thinking style. In other words, the use of fuzzy sets is more compatible with linguistic and sometimes ambiguous human explanations. Therefore, it is better to use long-term predictions and real-world decisions using fuzzy sets (using fuzzy numbers).

(iii) *PROMETHEE Method*: in recent years, the PROMETHEE method has been used to prioritize options, especially in crisis situations [44, 45]. Among the advantages of PROMETHEE method are comprehensibility, ability to deal with uncertainty, value decision-makers, visual display power of data, high reliability, and flexibility. Also, in higher versions of PROMETHEE (PROMETHEE 5) it is possible to apply restrictions to determine the optimal options [46].

3.1. Delphi Method. The Delphi method is an iterative process for gathering expert opinions; these experts are known to the panel members, whose only comments are published [47–49]. In this study, the panel members are health experts. Preliminary criteria were sent to members, and their opinions were collected. According to their views, the criteria were modified and sent to the panel members for the second time in the next step. In this study, the criteria are divided into preventive and operational, and a questionnaire has been developed for evaluation and comment. Preventive criteria are considered for evaluating emergency bases and functional criteria for assessing these centers' patient transport vehicles (ambulances). Table 2 shows the research criteria, which are divided into two parts: preventive and operational.

3.2. Weighting Criteria. Triangular fuzzy numbers (TFNs), which have a very high computational efficiency due to their simplicity and comprehensibility, were used in this study. Experts use this widespread weighting method, and it is more reliable. Each triangular fuzzy number consists of three values $F = (l \cdot m \cdot u)$ the upper bound u is the maximum value of fuzzy number F. The lower bound of l is the minimum value that a fuzzy number can bring, and m is the most probable value of a fuzzy number.

$$\mu_F(x) = \begin{cases} \dfrac{x-l}{m-l}, & l < x < m, \\ \dfrac{u-x}{u-m}, & m < x < u, \\ 0, & \text{otherwise}. \end{cases} \quad (1)$$

In this weighting step, the triangular fuzzy aggregation numbers are obtained according to the following formula [50]:

$$\begin{aligned} F_1 &= (l_1 \cdot m_1 \cdot u_1), \\ F_1 + F_2 &= (l_1 + l_2 \cdot m_1 + m_2 \cdot u_1 + u_2), \\ F_2 &= (l_2 \cdot m_2 \cdot u_2). \end{aligned} \quad (2)$$

3.3. Weighting Results. According to the set criteria and with experts' opinions, each of the criteria has been weighted. This weighting was determined by the triangular fuzzy aggregation method, and the criteria were defined in Excel software. The calculated weight is shown in Table 3. In the preventive weight section, the criteria for preventing the activity of suspicious personnel (0.91) and holding training sessions with weight (0.75) and in the operational area the weight measure or observe personal hygiene by the driver (1.00) and the car disinfection after operation criterion with weight (0.91) are one of the highest importance of criteria.

4. Sampling through the Morgan Table and Field Evaluation

Table 3 lists the operational criteria for field evaluation used to evaluate the patient transport vehicles (ambulance) for each research emergency base.

One of the easiest and most conservative ways to determine sample size is to use the Morgan table. To use this

Table 2: Standard criteria of Iran Health Organization.

Number	Criteria
1	Staff use N95 mask
2	Appropriate treatment equipment
3	Holding training sessions
4	Observe personal hygiene by the driver
5	Car cleaning facilities and equipment
6	Car disinfection after the operation
7	Proper ventilation system
8	Separate personnel health supplies
9	Use of special personnel
10	Prevents the activity of suspicious personnel

table, the target population size of Morgan table and sample size must be found [51]. Based on this, and using the information obtained, the number of patient transport vehicle operations in Sari, Iran, which were performed for one month, performs an average of 60 missions per day, and using the Morgan table, 52 sampling had to be done. The information of these evaluations is recorded daily and during the missions. For example, Ambulance B-1 (second emergency center) used a mask (N95) in 50 operations on the 30th day. After a field evaluation of the vehicles during a month, the average score obtained for each patient transport vehicle has been calculated. This average value indicates the level of compliance with the standard criteria of each vehicle during 30 days of sampling and field evaluation. Table 4 shows the results related to the first emergency and Table 5 shows the products related to the second emergency in full, which are given during a month.

4.1. Evaluation of the First and Second Emergency Centers. Based on the criteria of experts, a questionnaire was prepared to evaluate the prevention indicators of emergency centers. According to this questionnaire, emergency centers were evaluated for good performance and compliance with standards (Yes) and poor performance and noncompliance with standards (No). Table 5 shows the results of the performance evaluation of these centers in terms of compliance or noncompliance with health protocols.

5. Evaluation of the Results of Calculations

After determining the criteria and their weight by specialists, the evaluation of the transportation vehicles (Ambulance A-1, Ambulance A-2, Ambulance B-1, and Ambulance B-2) are performed using the PROMETHEE method. Quantitative results (Tables 4 and 6) and qualitative results (Table 5) of these evaluations are placed in a pairwise comparison matrix in Visual PROMETHEE software.

5.1. PROMETHEE Method. One of the main advantages of the PROMETHEE method is its simplicity and clarity. In this method, each of the criteria and weights can affect the answers, which shows the efficiency of this method. This method is used to make multicriteria decisions [52]. PROMETHEE I method gives the accurate ranking, and the PROMETHEE II

Table 3: Weighting of criteria by the triangular fuzzy aggregation method.

	Number	Criteria	Weight
Preventive	1	Holding training sessions	0.75
	2	Use of special personnel	0.63
	3	Prevents the activity of suspicious personnel	0.91
	4	Proper ventilation system	0.72
	5	Car cleaning facilities and equipment	0.63
Operational	1	Observe personal hygiene	1.00
	2	Car disinfection after the operation	0.91
	3	Separate personnel health supplies	0.75
	4	Staff use N95 mask	0.81
	5	Appropriate treatment equipment	0.85

Table 4: Evaluation of daily missions in compliance with health protocols in emergency center A.

Days/criteria	Ambulance A-1					Ambulance A-2				
	*C*1	*C*2	*C*3	*C*4	*C*5	*C*1	*C*2	*C*3	*C*4	*C*5
1	41	48	49	51	49	43	40	52	50	52
2	47	48	50	49	46	43	43	49	50	49
3	44	50	50	52	51	47	52	48	51	50
4	40	46	45	52	51	45	45	45	52	51
5	49	46	48	52	49	47	46	45	50	49
6	43	51	52	50	52	41	45	46	51	52
7	42	42	47	49	52	40	52	49	51	51
8	41	52	48	51	49	42	43	47	50	52
9	42	42	50	49	51	51	40	50	52	50
10	41	40	46	48	47	45	44	45	51	51
11	49	44	48	49	50	45	50	50	51	50
12	51	42	46	49	49	41	43	46	49	51
13	51	40	51	48	49	43	50	52	51	52
14	50	40	48	51	52	50	43	50	49	52
15	40	45	52	50	51	43	41	45	51	50
16	52	46	50	48	45	46	52	52	51	50
17	43	40	48	48	49	42	47	45	52	48
18	47	44	52	50	51	49	51	52	49	48
19	52	44	50	49	48	43	48	52	50	52
20	46	50	48	52	48	49	47	49	51	50
21	44	49	45	50	47	50	42	50	52	52
22	51	44	46	52	47	45	47	49	50	50
23	41	40	49	50	51	45	49	46	51	48
24	51	48	51	48	48	52	50	46	49	52
25	51	45	49	51	50	41	47	47	52	51
26	51	44	52	51	46	41	52	48	49	51
27	44	48	47	51	50	45	44	51	52	48
28	51	44	47	51	48	48	46	46	51	48
29	48	41	52	50	47	51	40	50	49	50
30	51	48	46	49	47	49	45	47	49	49
Average	46.5	45.0	48.7	50.0	49.0	45.4	46.1	48.3	50.5	50.3

method provides a complete ranking [53]. The PROMETHEE V method can also be used to consider problem constraints and evaluate the performance of options [54]. According to the objectives of this study, PROMETHEE II method was used to prioritize and evaluate options.

$$\max(\min a)\{f_1(a)\cdot f_2(a)\ldots f_k(a)|a\epsilon A\}. \tag{3}$$

A Set of Options. The $f_j(a)\cdot j = 1\ldots k$ shows the criteria against which the options are evaluated. The options are compared in pairs. This comparison is performed through a predefined priority function with ranges [0, 1]. For function *P*, there are options *b*. *a* and criterion *j*.

$$P_J(a\cdot b) = P_j\left[d_j(a\cdot b)\right], \tag{4}$$

so that $d_j(a\cdot b) = f_j(a) - f_j(b)$ shows the difference in sizes in the *j* index. The final ranking of the options is obtained through the following formula:

$$\pi(a\cdot b) = \sum_{j=1}^{k} W_j P_j(a\cdot b)\cdot\left(\sum_{j=1}^{k} W_j = 1\right), \tag{5}$$

Table 5: Evaluation of daily missions in compliance with health protocols in the emergency center B.

Days/criteria	Ambulance B-1					Ambulance B-2				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
1	46	48	46	50	52	43	51	46	50	51
2	45	45	45	52	50	42	35	48	52	52
3	45	50	46	52	50	49	44	46	49	52
4	52	52	48	50	52	50	41	52	51	51
5	49	50	46	51	51	41	46	46	50	51
6	46	50	52	52	49	42	44	50	50	51
7	51	51	44	51	48	40	48	50	51	50
8	49	49	46	51	49	50	36	45	50	51
9	46	48	47	50	49	48	49	45	50	51
10	45	47	44	51	48	45	39	51	51	51
11	52	50	44	50	52	45	43	49	50	51
12	51	46	50	51	52	50	45	46	51	50
13	51	52	47	52	49	48	47	45	52	50
14	50	51	51	50	48	41	36	49	52	52
15	45	50	44	51	52	42	38	50	50	52
16	51	50	44	50	52	46	44	51	51	51
17	50	49	50	50	48	52	41	52	52	52
18	49	48	50	49	49	51	43	50	50	51
19	46	52	43	51	52	51	51	47	52	51
20	52	48	44	49	50	43	43	46	49	51
21	49	49	43	49	52	51	52	48	49	50
22	45	52	47	52	48	40	43	52	51	52
23	47	49	51	52	48	40	52	48	52	52
24	47	49	45	50	52	42	39	50	51	51
25	49	46	49	49	50	44	47	50	51	52
26	45	47	47	49	52	40	36	51	52	51
27	50	50	49	49	51	51	47	51	52	52
28	47	52	45	50	51	46	40	45	49	50
29	45	46	52	49	52	48	35	46	49	51
30	47	49	46	52	47	51	44	45	50	51
Average	48.1	49.2	46.8	50.5	50.2	45.7	43	48.3	50.6	51

Table 6: Research operational criteria.

	Number	Criteria	Short name
Operational criteria	1	Observe personal hygiene	C1
	2	Car disinfection after the operation	C2
	3	Separate personnel health supplies	C3
	4	Staff use N95 mask	C4
	5	Appropriate treatment equipment	C5

where W_j is the standard weight determined by the decision maker and normalized by $(\sum_{j=1}^{k} W_j = 1)$ [55, 56]. For the $a\epsilon A$ option, the ranking stream is calculated by considering the other $x\epsilon A$ options.

The positive preference flow is as follows:

$$\varnothing^{+}(a) = \frac{1}{n-1}\sum_{x\epsilon A}\pi(x\cdot a). \quad (6)$$

Positive flow indicates better performance of one option than other options.

The negative preference flow is as follows:

$$\varnothing^{-}(a) = \frac{1}{n-1}\sum_{x\epsilon A}\pi(x\cdot a). \quad (7)$$

Unlike $\varnothing^{+}(a)$, this flow shows the poor performance of one option over the other [57]. For a complete ranking that simplifies the decision, it is possible to calculate the net flow [58].

$$\varnothing(a) = \varnothing^{+}(a) - \varnothing^{-}(a). \quad (8)$$

The input data for evaluating the options are the weight obtained from the criteria in Table 2, and the quantitative and qualitative values obtained from the field evaluation of the patient's vehicles are in Tables 4–6. Quantitative and qualitative values are considered as a pairwise comparison matrix for options and criteria. Emergencies were evaluated based on the optimal performance of patient transport vehicles of each center in compliance with health protocols.

Table 7: Results of the evaluation of preventive criteria of centers.

Number	Questions	Emergency center 1		Emergency center 2	
		Ambulance A-1	Ambulance A-2	Ambulance B-1	Ambulance B-2
1	Have coronavirus transmission training sessions been held for ambulance staff?	Yes	Yes	Yes	Yes
2	Are proper ventilation and ventilation system used in the car and terminal?	Yes	Yes	Yes	Yes
3	Are sick and suspected coronavirus personnel prevented from continuing their activities?	Yes	Yes	Yes	Yes
4	Are there enough detergents, disinfectants, car cleaning facilities, and equipment?	Yes	Yes	No	No
5	Are special personnel used as cleaners, and do these people use masks, gloves, boots, and work clothes when cleaning?	Yes	Yes	No	No

Table 8: Flow values calculated for patient transport vehicles by PROMETHEE.

Rank	Option	Phi	Phi+	Phi−
1	Ambulance B-1	0.1776	0.4129	0.2353
2	Ambulance A-2	0.0846	0.3664	0.2818
3	Ambulance A-1	−0.0888	0.2797	0.3685
4	Ambulance B-2	−0.1734	0.2374	0.4108

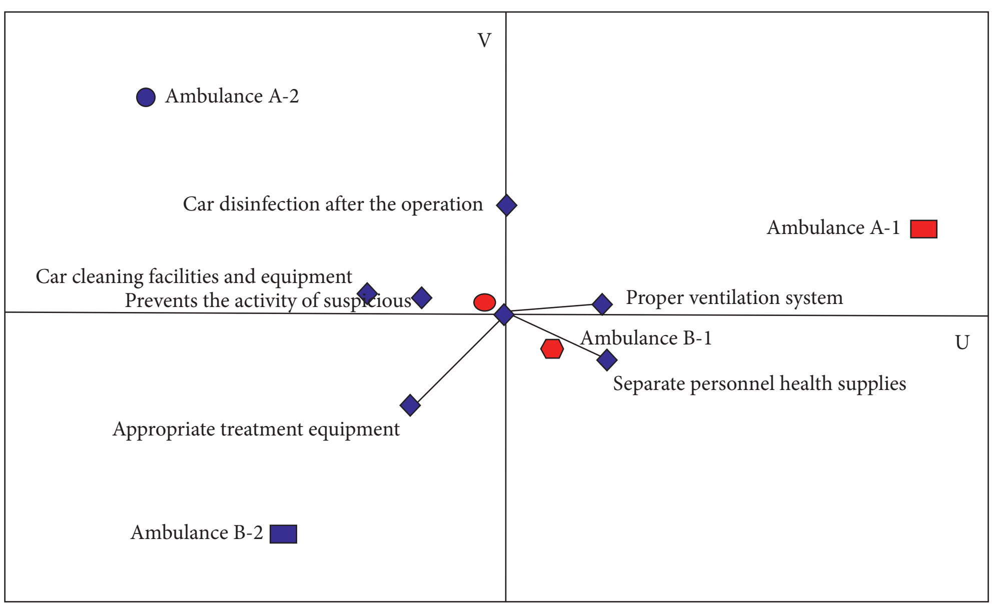

Figure 2: GAIA diagram of PROMETHEE.

6. Discussion

Table 7 is the output of PROMETHEE flow table. This table shows the positive (Phi +), negative (Phi−), and net Flow (Phi). Net is the balance of positive and negative flows. Each higher net indicates superior performance. In this way, the difference in performance between the two responses can be examined. As can be seen in Table 8, Ambulance B-1 (Phi = 0.1776) ranked first, Ambulance A-2 (Phi = 0.0846) ranked second, Ambulance A-1 (Phi = −0.0888) ranked third, and Ambulance B-2 (Phi = −0.1734) took the fourth place.

Figure 2 shows the GAIA chart. This chart has three different categories of information:

(1) Actions that are displayed with dots; (2) criteria in which the axes are displayed, and longer axis of the criteria is higher degree of importance; and (3) the weight of the criteria indicated by the decision axis. The length of each of them indicates the relative strength of the standard. The longer it is, the more critical that criterion is. On the other hand, the direction of an axis indicates where this criterion's best possible actions are located. In the GAIA diagram, the options that are

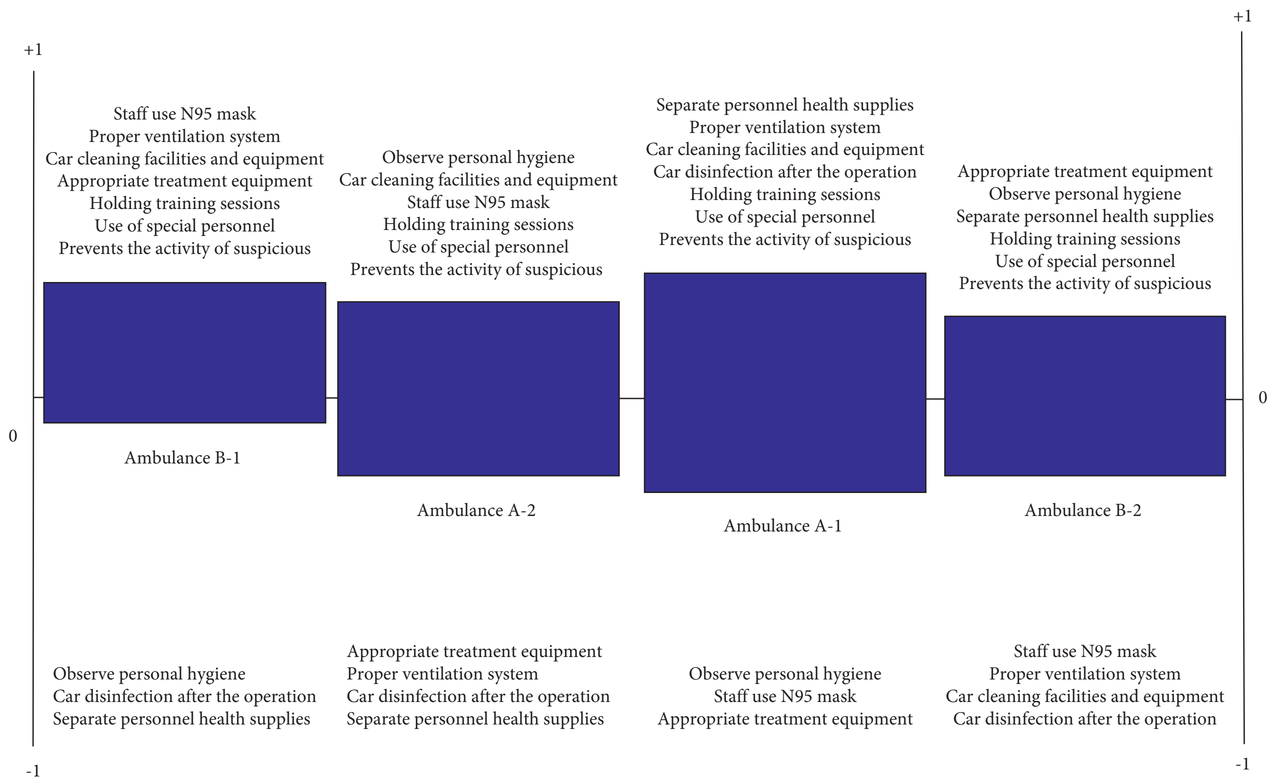

Figure 3: Rainbow diagram of PROMETHEE.

similar to each other are closer to each other. In displaying GAIA diagrams, the matching options are more relative to each other, and the conflicting options are farther apart. The criteria that have similar preferences are in the same direction, and the criteria that have inconsistent choices are in different directions. For example, Ambulance A-2 performs well in terms of car disinfection after operation and does not perform well in the standard of appropriate treatment equipment (due to being in the opposite direction of this standard).

Figure 3 is a rainbow diagram of a PROMETHEE output. This chart is a display of complete rankings. The sections at the top of the diagram show each option's positive attribute, and the sections at the bottom of the diagram show the opposing point of each option. In this diagram, ranking is done from left to right, and using this diagram, each option's performance and strengths and weaknesses can be determined. As shown in Figure 3, left-to-right Ambulance B-1 performed positively on seven criteria and negatively on three criteria. Also, the observed personal hygiene (1), car disinfection after operation (0.91), and separate personnel health supply (0.75) criteria had poor performance.

Figure 4 is a square corresponds to the page (Phi+, Phi−), where a dot indicates each option. Phi + scores increase from the left corner to the top corner, and phi- scores increase from the left corner to the bottom corner. For each option, a cone is drawn from the option position on the page. As can be seen, the Ambulance A-1 and Ambulance A-2 options have very similar functions, so that their performance axis overlaps. The reason for this can be considered the functional similarity in the criteria. This functional similarity has led to the convergence of the results of these two options. The high performance of the B-1 option in pure flow and positive flow has made it higher than other options in both the vertical axis and the left corner axis.

Finally, considering the amount of net flow (∅) and each option's performance score, each emergency center (Emergency A and Emergency B) is obtained. As shown in Figure 5, Emergency A (63%) performance was better. The reason for this center's superiority over Center B can be considered the better performance of this center in terms of prevention indicators (Table 5) and better performance of the center's vehicles (Ambulance A-1 and Ambulance A-2) in the performance index by observing the standards. Center B did not meet two of the five precautionary criteria. The center's vehicles (Ambulance B-1 and Ambulance B-2) performed poorly on many of the standard criteria of high weight importance, ultimately leading to poor performance.

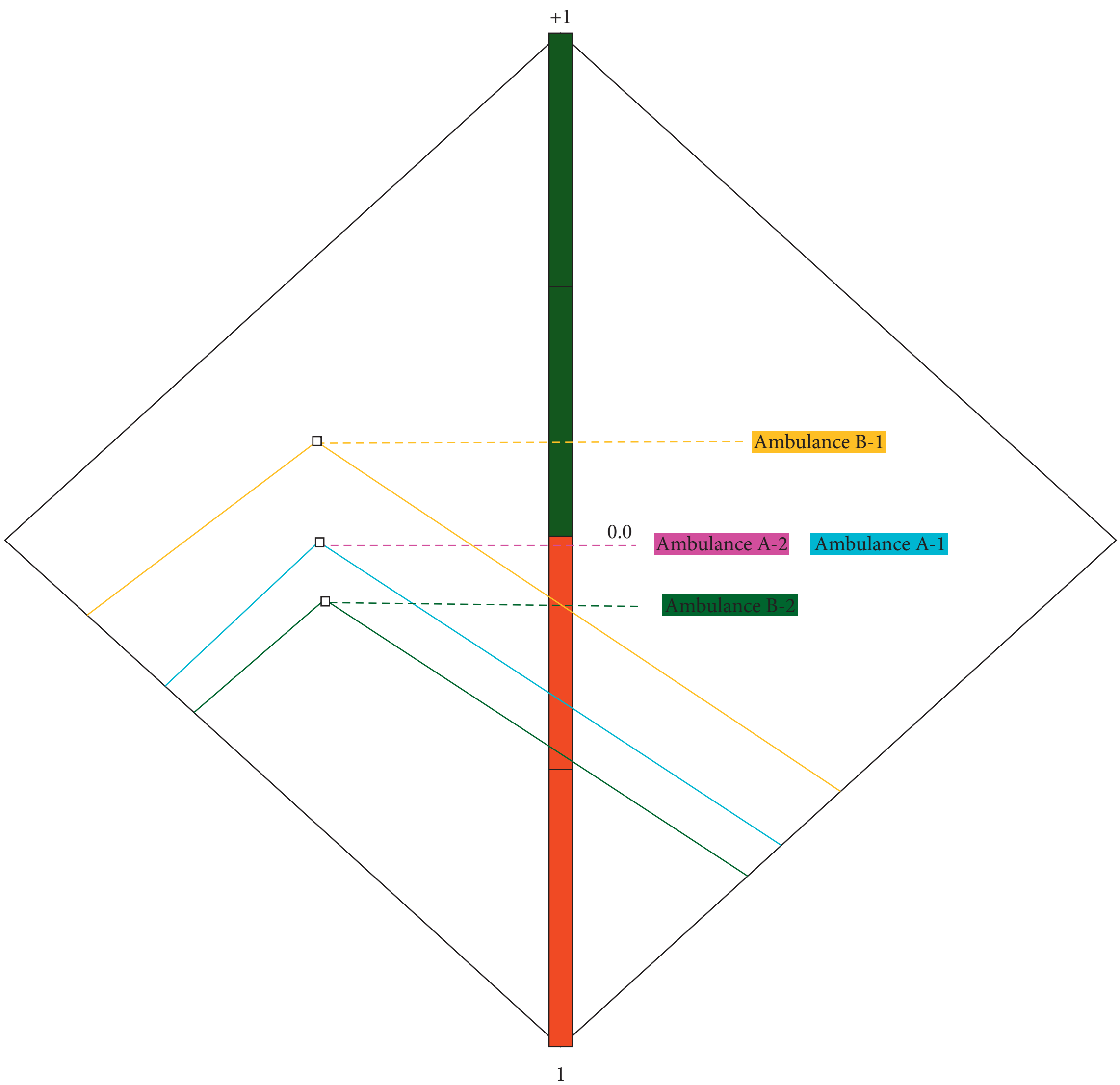

Figure 4: PROMETHEE output.

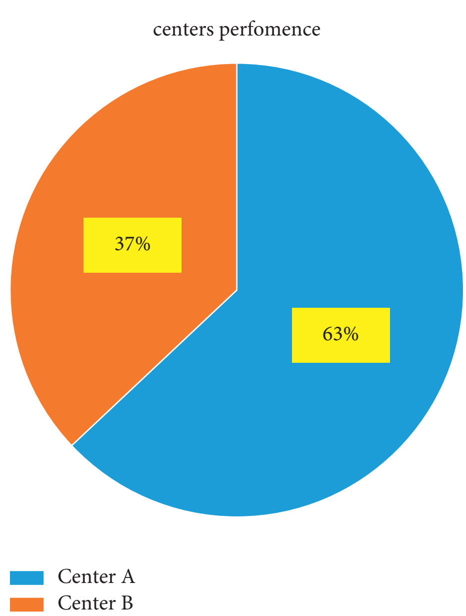

Figure 5: Performance of each center.

7. Conclusion

The purpose of this study was to evaluate emergency centers and vehicles carrying these centers at the time of coronavirus infection. First, with the cooperation of health experts and Delphi method, the criteria and subcriteria were identified and divided into operational and prevention. Then, the centers were evaluated based on preventive criteria, which included five criteria, and using the Morgan table and considering the average daily operations of each emergency, the number of samples of patient vehicle missions was determined. Each emergency station (each containing two vehicles) was evaluated daily by sampling. The results of these evaluations are evaluated and ranked using the PROMETHEE method as a binary comparison matrix. The results showed better performance of Center A (63%) due to proper performance and better compliance with protocols in both criteria (preventive and operational). The reason for the superiority of this center over Center B can be considered the better performance of this center in terms of prevention indicators and better performance of the center's vehicles (Ambulance A-1 and Ambulance A-2) in the performance index by observing the standards. The center has complied with all standards of preventive standards. The vehicles of this Center A-1 and Ambulance A-2 also had a positive performance in observing the performance indicators. Given the importance of emergency bases during an epidemic to control the disease and prevent the spread of the disease from treatment personnel to the patient and vice versa, the risk of vulnerability during service should be minimized by observing the set standards. By eliminating weaknesses and increasing strengths, relief bases can prevent disruption in the treatment and transmission of patients in severe epidemic conditions and minimize the possibility of vulnerability and transmission of the disease to medical staff and patients. According to the results, it can be concluded that in general the performance of the considered emergencies has been good in terms of operational and preventive criteria, and it can be concluded that these centers have been adapted to the epidemic conditions. The Ambulance B-2 option, which is ranked last in the ranking out of ten evaluation criteria, has a positive performance in 6 criteria and only in the criteria of staff use N95 mask, proper ventilation system, car cleaning facilities and equipment, and car disinfection after operation had poor performance, which with more management and stricter monitoring can be seen better performance in these criteria. Also, in the evaluation of the criteria by experts, the criteria of prevents the activity of suspicious personnel and car disinfection after the operation were of higher weight (0.91) than other criteria, which were performed by regular virus identification test and timely identification of emergency personnel and car disinfection. The patient can lead to better performance of emergency centers during an epidemic. The Crisis Management Organization, the Red Crescent, and the emergency centers are among the organizations that can address structural and operational problems during an epidemic by considering the results of in-depth management research and studies. This research can help relevant organizations and centers minimize financial and human losses in the event of an epidemic. In general, the research results include the following:

(i) The results showed better performance of Center A (63%) due to proper performance and better compliance with protocols in both criteria (preventive and operational).

(ii) In the evaluation of the criteria by experts, the criteria for preventing the activity of suspicious personnel and postoperative car disinfection had a higher weight (0.91) than other criteria.

(iii) According to the results, it can be concluded that in general the performance of the considered emergencies has been good in terms of operational and preventive criteria, and it can be concluded that these centers have been adapted to the epidemic conditions.

(iv) Disinfection of staff and sick vehicles can lead to better performance of emergency centers during an epidemic.

Lack of access to experts for face-to-face evaluation and noncooperation of some emergency centers to record information due to the epidemic conditions have been the limitations of this study. Also, due to epidemic conditions, it has been tried to exchange information online as much as possible, and due to special restrictions, it was not possible to receive operational information at longer intervals. In addition to emergency centers, hospitals and relief centers are also recommended. It is also recommended to check the performance of emergency centers under normal conditions and compare it with epidemic conditions to identify the effective factors and take action to better manage the epidemic.

Data Availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Optimizing Resource-Constrained Project Scheduling Problem considering the Reliability Function

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Resource-constrained project scheduling has been a significant and practical problem in recent decades. In this research, besides previous assumptions and models regarding scheduling, the reliability function with a novel approach is included in the model. A new look at the project scheduling problem is pursued by studying the probability of access to renewable resources. The mentioned problem programming model is a mixed nonlinear mathematical model that uses the properties of an exponential function to become a linear programming model, exact optimization software is used to solve it in smaller dimensions, and a genetic algorithm is used to solve it in NP-hard dimensions. The algorithms and statistical analysis results at a 95% confidence level show the proper performance of the genetic algorithm; therefore, this algorithm is more efficient for the proposed model. Using the provided mathematical model, this research leads to decreasing time and lags, decreasing costs, and increasing reliability in multimode activities.

1. Introduction

Certainly, the issue of resource-constrained project scheduling is one of the most widely used scheduling issues; other scheduling problems are a subset of this issue [1]. The problem of resource-constrained project scheduling seeks a suitable sequence for performing activities of a project so that constraints such as project network precedence constraints and various types of resource constraints in the project are provided simultaneously, and certain measurement criteria including project implementation time, implementation cost, and number of lagged activities are optimized. These types of problems are of great importance in scientific and practical dimensions [2].

Projects in many countries play a very important role in national development and economic recovery. Economic growth in such countries is due to the implementation of projects. In general, projects carried out at the national level have large dimensions, and large budgets must be allocated for their implementation. Therefore, optimal management has led to successful project implementation, increased revenues, and reduced costs. Therefore, this management must be done carefully and correctly [2]. The issue of project scheduling has been limited in the subject literature. These constraints are mainly considered as resource type and are known as resource-constrained project scheduling problem (RCPSP). In the classic version, RCPSP aims to provide an optimal schedule for the sequence of activities under resource constraints so as to minimize project execution time. The resources used in the classic version are considered as the renewable type [3].

In the last decade, the issue of project scheduling has been studied and developed from various aspects. These developments cover various aspects of this issue. Providing different linear and nonlinear models for this problem, single-state or multistate and intermittent or non-intermittent activities, existence of resources of different types (in most cases renewable and nonrenewable resources), various objective functions, and certainty or uncertainty of the parameters of the problem are considered from different dimensions of the problem [1].

The main contributions of this research are as follows:

(i) In the RCPSP model provided in this research, in addition to previous assumptions and constraints, reliability is considered as a new and practical concept.

(ii) We express the probability of the availability of renewable resources by maximizing reliability, and as a result, the associated constraints are added to the model.

(iii) The model considers multiobjective functions of cost, time, and reliability.

(iv) Constraints associated with reliability have led to the nonlinearity of the model, which is eventually presented as a linear model.

(v) Since the scheduling optimization model has its complexities with limited resources, in this research, the genetic metaheuristic algorithm will be used to solve the proposed mathematical model.

(vi) The obtained optimal solutions will be compared with the final solutions of the exact method.

2. Literature Review

Various models have been developed to solve project scheduling problems and divided into several different branches. Kolisch et al. [3] have proposed a fuzzy critical chain method for resource-constrained project scheduling in conditions of uncertainty and have used project buffer to cope with uncertainty. Pan et al. [4] investigated resource-constrained project scheduling. Instead of using the traditional tabu search method and other methods based on artificial intelligence, this paper uses the improved tabu search method to modify the initial response generation method instead of the traditional method. Chen and Askin [5] used a combination of genetic algorithms and simulated annealing to solve the simultaneous multiproject scheduling problem and investigated the performance of the proposed method in three different case studies. Kyriakidis et al. [6] used mixed-integer linear programming models to formulate single-state and multistate project scheduling problems and the resource-task network approach used in scheduling problems to represent. Paraskevopoulos et al. [7] used the event view display approach considering the constraints that may occur in the process due to the use of activity lists and random number methods. They used the scatter search-based algorithm equipped with an adaptive iterated local search technique to solve the problem.

Bruni et al. [8] investigated the resource-constrained project scheduling in situations where the duration of activities is uncertain and used independent random variables with a known distribution function to indicate the possibility of uncertainty in the duration of activities, that is, used the possible planning framework in the form of possible common constraints. Finally, according to the level of confidence considered by the decision-maker, problems with a different number of activities were examined. It was proved to be better controlled by dealing more strictly with uncertainty.

Pan et al. [4] addressed the resource-constrained project scheduling problem; instead of using the traditional tabu search method and other methods based on artificial intelligence, they used the improved tabu search method by modifying the initial response generation method. We can also refer to cases that have simultaneously studied the problem of portfolio selection and scheduling. For example, we can refer to studies conducted by [5, 9]. But the point is that most of these studies have mainly focused on the selection aspect and less on the potential effects of different procurement strategies and annual budgets on resource allocation. For example, in the first planning year/period, the company may have a certain number of cranes. This number will decrease or increase in the following year/period according to the desired policies.

For this reason, Liu et al. [10] provided an optimization model using constraint planning for selection problems and scheduling with time-dependent constraints and proposed a general model for maximizing the total profit of the selected research and development construction projects. Issues such as relationships and incompatibilities between projects have also been considered. However, all the assumptions are related to certain conditions, the projects are considered in a single set, and the details of the activities are not considered in the review. It is noteworthy that the scheduling problem in the case of time-dependent resources was raised by Tautenhahn et al. [11], in which the amount of access to resources changes over time.

Bouleimen et al. [12] provide an efficient simulated annealing algorithm for a resource-constrained problem with different modes to do the job. The objective is to minimize the duration of the project. They used two common loops in the simulated annealing method and a project search mode. Other approaches have been proposed in project planning and design in addition to the issues that concern the minimization of project completion time. Cash flow management is one of these views that will bring benefits such as cost control and profit for contractors. For example, Liu et al. [10] used constraint planning to maximize the net present value of project cash flows.

Tirkolaee et al. [13] carried out a study on the multiobjective optimization of resource-constrained project scheduling in multimode context. They used Pareto-based algorithms. The problem objectives included maximizing net present value and minimizing time to complete activities. They used nonlinear programming that solved numerical problems using the GAMS-BARON solver and the Epsilon constraint method. Balouka et al. [14] provided a robust optimization approach to the resource-constrained project scheduling problem. New Benders' cuts led to new selections and allocations of resources. Uncertain sets of parameters also depend on the selection of modes. Chakrabortty et al. [15] provided the multimode resource-constrained project scheduling problem using the variable neighborhood search metaheuristic method. They provided a near-optimal quick solution to the proposed problem. Tao et al. [16] provided resource-constrained project scheduling with alternative project structures. In their research, an AND-OR network was presented for the problem, and the two-objective mixed-

Table 1: Summary of literature review.

Year	Reference	Objectives	Main considerations	Solution method
2008	Pan et al.	Resource-constrained project scheduling	Modifying the initial response generation method	Improved tabu search method
2009	Chen et al.	Multiproject scheduling problem		Genetic algorithm, simulated annealing
2011	Bruni et al.	Resource-constrained project scheduling	Uncertain duration of activities	Distribution function
2012	Paraskevopoulos et al.	Scheduling	Using activity lists and random number methods	Scatter search-based algorithm equipped with an adaptive iterated local search technique
2012	Liu et al.	An optimization model, maximizing the total profit	Selection problems and scheduling with time-dependent constraints	Heuristic
2018	Tao et al.	Cost and total profit	Resource-constrained project scheduling with alternative project structures	Two-objective genetic method and tabu search
2019	Tirkolaee et al.	Maximizing net present value and minimizing time	Multiobjective optimization of resource-constrained project scheduling in multimode context	Pareto-based algorithms
2020	Chakrabortty et al.	Multimode resource-constrained project scheduling		Variable neighborhood search metaheuristic
2021	Balouka et al.	A robust optimization approach to the resource-constrained project scheduling		New Benders' cuts
2021	Yuan et al.	A multiobjective project scheduling	Fuzzy activities	Self-adaptive mechanism and self-adaptive selection process
2021	Lotfi et al.	Robust time-cost-quality-energy-environment trade-off	Resource-constrained project scheduling	Robust optimization
2022	Saad et al.	Discovery/extraction, diversity, and intensification		Quantum-based genetic algorithm, evolutionary method of genetics
2022	Bulavchuk et al.	Net present value, finding acceptable schedules	Multivariate vectors	Genetic algorithm based on algebraic methods

integer linear programming of the problem with a balance between cost and total profit was provided. To solve the problem, a two-objective genetic method and tabu search were used. In their paper, Xie et al. [17] presented an optimization model for scheduling projects under uncertainty of activity cost. Their method helps a device obtain accurate answers to the problem, and a hybrid approach and genetic algorithm are used. Yuan et al. [18] modeled a multiobjective project scheduling problem with fuzzy activities. The proposed interval values are considered of execution time for activities as fuzzy theory. Also, is the collaborative evaluation framework with a self-adaptive mechanism and the self-adaptive selection process.

More recent related research in this area includes research conducted by [19–21]. However, resource-constrained problems have been used in many problems. In project scheduling problems, a set of activities is considered by observing the sequence of performing them, and restrictions on access to renewable and nonrenewable resources and different modes of activities are considered in the model studied in that research.

Saad et al. [22] solved the resource-constrained project scheduling problem using a quantum-based genetic algorithm. The optimal solution to RSPSP problems requires a balance between discovery/extraction, diversity, and intensification. With this viewpoint, the evolutionary method of genetics can improve the population and the quality of solutions. It investigates the performance of a quantum-based genetic algorithm and can be used for resource-constrained scheduling problems. The quantum-based genetic algorithm is similar to the classical genetic algorithm, but the updated and initial populations are implemented using quantum situations. Bulavchuk et al. [23] used a genetic algorithm based on algebraic methods for RCPSP. They used resource constraints and a criterion for net present value. Furthermore, acceptable schedules were found by solving linear equations. In the genetic algorithm used in their research, multivariate vectors were used to describe individuals in the population. Their computational results and research findings show the efficiency of the genetic algorithm. Asadujjaman et al. [24] used a secure genetic algorithm to solve the resource-constrained project scheduling problem based on NPV. They used a combined genetic method with a secure algorithm to improve the performance of all components. The performance of the IGA algorithm used was improved by adding variables based on local search and backward implementation. Table 1 shows a summary of the literature review.

In the RCPSP model provided in this research, in addition to previous assumptions and constraints, reliability is considered as a new and practical concept, in the sense that we express the probability of the availability of renewable resources by maximizing reliability, and as a result, the associated constraints are added to the model. The model considers multiobjective functions of cost, time, and reliability. Constraints associated with reliability have led to the nonlinearity of the model, which is eventually presented as a linear model. Since the scheduling optimization model has its complexities with limited resources, in this research, the genetic metaheuristic algorithm will be used to solve the proposed mathematical model. The obtained optimal solutions will be compared with the final solutions of the exact method. This section reviews the main research works on resource-constrained project scheduling problem. Section 3 provides the modeling of the problem, its constraints, variables, and parameters. In Section 4, we provide numerical examples and solve them in LINGO software and genetic metaheuristic algorithm and compare the results obtained from both methods. In the last section, we provide conclusions and suggestions for future research.

3. Problem Modeling

First, to express the basic model in the RCPSP, we define the sets, variables, and parameters used in this research. In this research, we want to investigate the resource-constrained project scheduling in several periods, including several activities with several different modes for each activity. Project resources are also divided into renewable and nonrenewable. Decisions made after solving the mathematical model include whether or not to start an activity in a particular situation and the need or no need for a renewable resource with a certain amount in a situation where a certain amount of it was initially available in the project. Additionally, in this problem, the duration of each activity in the project will be specified. Finally, the minimum amount of lags in the scheduling project is calculated in the optimal state after determining the problem decisions. It should be noted that the main objective of this problem is to minimize the number of lags in project scheduling for existing activities and, at the same time, to make the said decisions optimally.

3.1. Sets

I: Set of activities.

M: Set of available modes.

K: Set of renewable resources.

L: Set of nonrenewable resources.

T: Set of periods.

3.2. Parameters

TC: Total cost.

MS: Lags.

R: Reliability.

t: Time.

$N^r_{k,t}$: Number of the K renewable resources on the tth day.

$r^r_{i,m,k}$: Units required from the Kth renewable resource ($K \in R$).

a^n_k: Number of Kth renewable sources.

$r^r_{i,m,l}$: Units required from the Lth nonrenewable resource ($I \in R^n$).

a^n_l: Number of Lth nonrenewable resources.

$R^r_{k,t}$: Reliability (probability of availability) of the Kth renewable resource to the required number on the tth day.

P^r_k: Probability of availability of Kth renewable resource.

u^r_k: The upper limit of the Kth renewable resource.

l^r_k: The lower limit of the Kth renewable source.

c^r_k: Cost per unit of renewable resource.

c^n_k: Cost per unit of nonrenewable resource on all days and all consumable resources available.

3.3. Variables. $X_{i,m,t} = \begin{cases} 1 \\ 0 \end{cases}$ if activity i starts in state m and at time t.

$Y^r_{k,a',t,N'} = \begin{cases} 1 \\ 0 \end{cases}$ if the kth renewable resource on the tth day is needed as N' in a situation where there is generally enough of a' from that resource at the beginning of the project.

$d_{i,m}$: Duration of performing activity i in state m.

In the following, we explain the objective function and constraints of the basic model of the resource-constrained project scheduling problem:

$$\text{Minimize} \sum_{t=es_{n+1}}^{ls_{n+1}} t x_{n+1,1,t}, \tag{1}$$

s.t.,

$$\sum_{m=1}^{M_i} \sum_{t=es_i}^{ls_i} \left(t + d_{i,m}\right) x_{i,m,t} \leq \sum_{m=1}^{M_j} \sum_{t=es}^{ls_i} t x_{j,m,t} \,\forall (i,j) \in A, \tag{2}$$

$$\sum_{m=1}^{M_i} \sum_{t=es_i}^{ls_i} x_{i,m,t} = 1 \,\forall i \in N, \tag{3}$$

$$\sum_{i=1}^{n} \sum_{m=1}^{M_i} r^r_{i,m,k} \sum_{s=\max\left(t-d_{i,m}, es_i\right)}^{\min\left(t-1, ls_i\right)} x_{i,m,s} \leq a^r_k \,\forall k \in R^r \text{ and } t = 1, \ldots, T, \tag{4}$$

$$\sum_{i=1}^{n} \sum_{m=1}^{M_i} r^n_{i,m,l} \sum_{t=es_i}^{ls_i} x_{i,m,t} \leq a^n_l \,\forall l \in R^n x_{i,m,t} \in \{0,1\} \,\forall i \in N, m = 1, \ldots, M_i, t = 1, \ldots, T. \tag{5}$$

The objective function (1) is expressed as the minimum lags. Constraint (2) shows the sequence of performing activities considering their prerequisite constraints with lag = 0. Constraint (3) guarantees that each activity is performed in one mode and at a time by spending the resources to perform that activity in the same particular model. Constraints (4) and (5) indicate the limitation of access to renewable and nonrenewable resources (the definition of variables is given at the end of the model).

In the following, the model studied in this research considers the reliability functions that have been investigated to the possibility of accessibility of renewable resources. Subsequent constraints have also been added to the model and are described below.

The nonlinear multiobjective RCPSP model is as follows:

$$\text{Min}\, TC, \tag{6}$$

$$\text{Min}\, MS, \tag{7}$$

$$\text{Max}\, R_{\text{total}}\ \text{s.t}, \tag{8}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i}\left(t+d_{i,m}\right)x_{i,m,t} \le \sum_{m=1}^{M_j}\sum_{t=es}^{ls_i} tx_{j,m,t}\,\forall\,(i,j)\in A, \tag{9}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i} x_{i,m,t}=1, \forall i\in N, \tag{10}$$

$$N^r_{k,t}=\sum_{i=1}^{n}\sum_{m=1}^{M_i} r^r_{i,m,k}\sum_{s=\max\left(t-d_{i,m},es_i\right)}^{\min\left(t-1,ls_i\right)} x_{i,m,s}\,\forall k\in R^r\ \text{and}\, t=1,\ldots,T, \tag{11}$$

$$N^r_{k,t}\le a^r_k, \forall k\in R^r\ \text{and}\, t=1,\ldots,T, \tag{12}$$

$$L^r_k\le a^r_k\le U^r_k, \forall k\in R^r, \tag{13}$$

$$\sum_{i=1}^{n}\sum_{m=1}^{M_i} r^n_{i,m,l}\sum_{t=es_i}^{ls_i} x_{i,m,t}\le a^n_l, \forall l\in R^n, \tag{14}$$

$$R^r_{k,t}=\sum_{g=N^r_{k,t}}^{a^r_k}\binom{a^r_k}{g}.\left(p^r_k\right)^g.\left(1-p^r_k\right)^{a^r_k-g}, \forall k\in R^r\ \text{and}\, t=1,\ldots,T, \tag{15}$$

$$\sum_{t=es_{n+1}}^{ls_{n+1}} tx_{n+1,1,t}, \tag{16}$$

$$TC=\sum_{t=1}^{T}\sum_{k\in R^r} C^r_k.a^r_k+\sum_{t=1}^{T}\sum_{i=1}^{n}\sum_{m=1}^{M_i}\sum_{l\in R^n} C^n_l.r^n_{i,m,l}.x_{i,m,t}, \tag{17}$$

$$R_{\text{total}}=\prod_{t=1}^{T}\prod_{k\in R^r} R^r_{k,t}, x_{i,m,t}\in\{0,1\}, \forall i\in N, m=1,\ldots,M_i, t=1,\ldots,T, a^r_k\in Z, \forall k\in R^r. \tag{18}$$

The objective function is expressed as a multiobjective function of cost minimization, time lag minimization, and reliability maximization. Constraints (9) and (10) are the basic constraints (RCPSP), as described earlier. Constraint (11) indicates the required number of the kth renewable resources on the tth day. Constraint (12) states that the number of kth renewable resources on the tth day is less than the total number of the kth renewable resources. Constraint (13) is the inherent constraint of the kth renewable resource, which is confined between the upper and lower limits. Constraint (14) is the inherent constraint of access to nonrenewable resources. Constraint (15) is related to the reliability of the project and expresses the possibility of accessibility and selection of renewable resources from existing resources with the binomial distribution. Constraint (16) shows the total time lags. Constraint (17) represents the project's total cost, which is the sum of the costs of renewable and nonrenewable resources. Constraint (18) indicates the total reliability of the project; for example, the reliability of a renewable resource is obtained from the probability of its accessibility at time 1, . . ., T.

This multiobjective model is nonlinear due to constraints (15) and (18). We used exponential function properties to linearize it and added the variable $\gamma^r_{k,a',t,N'}$ to the model according to the definition given in the introduction of the variables.

Linearization is as follows:

$$\begin{aligned} L_n\left(R_{\text{total}}\right) &= L_n\left(\prod_{t=1}^{T}\prod_{k\in R^r} R^r_{k,t}\right)\\ &=\sum_{t=1}^{T}\sum_{k\in R^r} L_n\left(R^r_{k,t}\right),\end{aligned} \tag{19}$$

$$\begin{aligned}&\gamma^r_{k,a',t,N'}=L_n\left(R^r_{k,t}\right),\quad \text{if}, a^r_k=a'\ \text{and}\, N^r_{k,t}=N',\\ &\gamma^r_{k,a',t,N'}=\ln\left(\sum_{g=N'}^{a'}\binom{a'}{g}.\left(p^r_k\right)^g.\left(1-p^r_k\right)^{a'-g}\right),\\ &\forall k\in R^r, \text{and}\, t=1,\ldots,T, a'=L^r_k,\ldots,\\ &U^r_k\ \text{and}\, N'=0,\ldots,a'.\end{aligned} \tag{20}$$

Linear multiobjective RCPSP model is as follows:

$$\text{Min}\, TC, \tag{21}$$

$$\text{Min}\, MS, \tag{22}$$

$$\text{Max}\, R_{\text{total}}\ \text{s.t}, \tag{23}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i}\left(t+d_{i,m}\right)x_{i,m,t}\le\sum_{m=1}^{M_j}\sum_{t=es}^{ls_i} tx_{j,m,t},\quad \forall\,(i,j)\in A, \tag{24}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i} x_{i,m,t}=1, \forall i\in N. \tag{25}$$

$$\begin{aligned} N^r_{k,t} &= \sum_{i=1}^{n}\sum_{m=1}^{M_i} r^r_{i,m,k}\sum_{s=\max\left(t-d_{i,m},es_i\right)}^{\min\left(t-1,ls_i\right)} x_{i,m,s},\\ &\forall k\in R^r\ \text{and}\, t=1,\ldots,T,\end{aligned} \tag{26}$$

$$N^r_{k,t}\le a^r_k, \forall k\in R^r\ \text{and}\, t=1,\ldots,T, \tag{27}$$

$$L_k^r \le a_k^r \le U_k^r, \quad \forall k \in R^r, \tag{28}$$

$$\sum_{i=1}^{n}\sum_{m=1}^{M_i} r_{i,m,l}^n \sum_{t=es_i}^{ls_i} x_{i,m,t} \le a_l^n, \ \forall l \in R^n, \tag{29}$$

$$MS = \sum_{t=es_{n+1}}^{ls_{n+1}} t x_{n+1,1,t}, \tag{30}$$

$$TC = \sum_{t=1}^{T}\sum_{k\in R^r} C_k^r.a_k^r + \sum_{t=1}^{T}\sum_{i=1}^{n}\sum_{m=1}^{M_i}\sum_{l\in R^n} C_l^n.r_{i,m,l}^n.x_{i,m,t}, \tag{31}$$

$$R_{total} = \sum_{t=1}^{T}\sum_{k\in R^r}\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=a'}^{U_k^r} \gamma_{k,a',t,N'}^r \cdot y_{k,a',t,N'}^r, \tag{32}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r = 1, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{33}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r.N' = N_{k,t}^r, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{34}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r.a' = a_k^r, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{35}$$

$$x_{i,m,t} \in \{0,1\}, \quad \forall i \in N,\ m = 1,\ldots,M_i, t = 1,\ldots,T, \quad a_k^r \in Z,\ \forall k \in R^r. \tag{36}$$

Finally, the single-objective model to minimize lags is provided below.

Linear single-objective RCPSP model is as follows:

$$\text{Min } MS \text{ s.t,} \tag{37}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i}\left(t + d_{i,m}\right)x_{i,m,t} \le \sum_{m=1}^{M_j}\sum_{t=es}^{ls_i} t x_{j,m,t}, \ \forall (i,j) \in A, \tag{38}$$

$$\sum_{m=1}^{M_i}\sum_{t=es_i}^{ls_i} x_{i,m,t} = 1, \ \forall i \in N, \tag{39}$$

$$N_{k,t}^r = \sum_{i=1}^{n}\sum_{m=1}^{M_i} r_{i,m,k}^r \sum_{s=\max\left(t-d_{i,m},es_i\right)}^{\min\left(t-1,ls_i\right)} x_{i,m,s}, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{40}$$

$$N_{k,t}^r \le a_k^r, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{41}$$

$$L_k^r \le a_k^r \le U_k^r, \quad \forall k \in R^r, \tag{42}$$

$$\sum_{i=1}^{n}\sum_{m=1}^{M_i} r_{i,m,l}^n \sum_{t=es_i}^{ls_i} x_{i,m,t} \le a_l^n, \quad \forall l \in R^n, \tag{43}$$

$$MS = \sum_{t=es_{n+1}}^{ls_{n+1}} t x_{n+1,1,t}, \tag{44}$$

$$TC = \sum_{t=1}^{T}\sum_{k\in R^r} C_k^r.a_k^r + \sum_{t=1}^{T}\sum_{i=1}^{n}\sum_{m=1}^{M_i}\sum_{l\in R^n} C_l^n.r_{i,m,l}^n.x_{i,m,t}, \tag{45}$$

$$L_n\left(R_{\text{total}}\right) = \sum_{t=1}^{T}\sum_{k\in R^r}\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} \gamma_{k,a',t,N'}^r \cdot y_{k,a',t,N'}^r, \tag{46}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r = 1, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{47}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r.N' = N_{k,t}^r, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{48}$$

$$\sum_{a'=L_k^r}^{U_k^r}\sum_{N'=0}^{a'} y_{k,a',t,N'}^r.a' = a_k^r, \quad \forall k \in R^r \text{ and } t = 1,\ldots,T, \tag{49}$$

$$TC \le TC_{\max}, \tag{50}$$

$$L_n\left(R_{\text{total}}\right) \ge L_n\left(R_{\min}\right), \tag{51}$$

$$x_{i,m,t} \in \{0,1\}, \quad \forall i \in N, m = 1,\ldots,M_i,\ t = 1,\ldots,T, \quad a_k^r \in Z, \quad \forall k \in R^r, \quad L_n\left(R_{\text{total}}\right) \in \text{free}. \tag{52}$$

4. Solution Method (Genetic Algorithm)

4.1. Early Population. To use genetic methods, the first step is to create an early population called a chromosome. Since this method is affected by population size, this parameter should be considered as one of the basic parameters in this method. If this population is too small, this method will not be able to produce qualified answers, and if this population is large, the solution time of this method will be very long, and as a result, this method will take more time. To determine the effective population size, the two main parameters of intersection rate and mutation rate must be adjusted accordingly.

4.2. Selection. There are two different methods for selecting parents in the genetic method. A percentage of parents are selected through a competition approach, and the rest are selected from the best practical solutions of current

Table 2: Numerical examples in different dimensions.

Number of a numerical example	Number of activities	Number of modes	Number of renewable resources	Number of nonrenewable resources	Number of working days
1	2	2	3	2	5
2	4	3	5	3	6
3	6	3	7	3	8
4	8	3	9	4	15
5	12	4	10	5	20
6	16	4	12	5	25
7	20	4	13	6	30
8	22	5	14	6	35
9	23	5	15	6	45
10	24	5	16	7	50

generations. The second method ensures the characteristics of qualified solutions that are passed on to the next generation. In addition, this method provides more accuracy and prevents the rapid convergence of the genetic method.

4.3. Genetic Operators. The production process in the genetic algorithm is performed using cross operators and mutations on selected parents. Cross operators combine the characteristics of two parents. Several types of these operators are offered for different issues. In the genetic algorithm, the mutation operator prevents the rapid convergence of genetic responses. To perform a mutation in a genetic algorithm, two cells are randomly selected, and then their values are swapped.

4.4. Adaptive Uniform Mutation. For this operator, the nonlinear function P_m, with respect to iterations, is created to control the probability and amplitude of the mutation for each particle. This function is updated in each iteration based on the following method:

$$P_m = 0.5 * e^{(-10*t/T)}. \tag{53}$$

T represents the maximum repetition times. According to this equation, the value of P_m decreases with increasing iterations. If P_m is higher than a random number between 0 and 1, the current particle mutation is calculated as follows. First the K elements are randomly selected from this particle, and then the values of these elements are re-quantified in the search space. The value of K is followed as an integer calculated to control the amplitude of the mutation:

$$K = \max\{1, [D * P_m]\}. \tag{54}$$

4.5. Local Learning Strategy. Local learning strategy is a local method based on differential learning to study areas with sparse solutions in each space to enhance the performance of the algorithm. In this method, first of all, the best solution is selected by X_{best} as the base vector. Then, based on X_{n1} and X_{n2}, two random solutions are set as differential vectors. In the last step, by adding the difference between X_{n1} and X_{n2} to the base vector X_{best}, the new answer is obtained as follows:

$$X_i' = X_{\text{best}} + F.\left(X_{n1} - X_{n2}\right). \tag{55}$$

This process is repeated until N new solution is generated. F is the scale factor for improving the variety of new solutions, ranging from 0.1 to 0.9.

5. Solving the Problem and Providing Numerical Results

This section will solve the single-objective problem using LINGO software and a genetic metaheuristic algorithm. The optimal values of the model costs obtained in this software and the genetic metaheuristic approach are compared. First, we design numerical examples as follows.

According to Table 2, it is clear that with increasing the dimensions of the numerical problem, the number of activities, the number modes, the number renewable and nonrenewable resources, and the number of working days as the number of planning periods also increase. Thus, we solve the problem in each of the ten different dimensions.

The values of the functions obtained from the exact method in LINGO software and the genetic approach are reported in Table 3. It can be concluded that in numerical examples with small dimensions, the exact method performed better than the genetic algorithm. For numerical examples 1, 2, and 3, the costs obtained from the exact method are less than those from the genetic method. On the other hand, in numerical examples with high dimensions and from example number 3 onwards, it can be seen that the genetic metaheuristic approach performed better in optimizing costs than the exact method. In addition, it can be seen that from numerical example 7 onwards, the exact method is not able to solve the problem. In this case, the genetic approach is more appropriate. Furthermore, in the right column, the difference in the optimality of the objective functions of the two methods can be seen.

Figure 1 shows the amount of change in the objective function in both the genetic method and the LINGO software. It is observed that with an increasing dimension of the problem, the performance of the genetic algorithm improves compared to LINGO software. From numerical example 7 onwards, using the genetic algorithm is better, and it can be used to solve large-dimension problems.

Table 3: Objective function values using exact and genetic methods.

Numerical example	Objective function (exact method in LINGO software)	Objective (genetic) function	Difference between the optimal values in the two methods
1	25.6	27	5.18
2	75.6	100.4	24.7
3	210.6	220.7	4.57
4	654.3	541.6	17.22
5	1657.9	1543.8	6.88
6	3475.2	3257.6	6.27
7	—	4116.7	—
8	—	5569.2	—
9	—	6578.6	—
10	—	7982.3	—

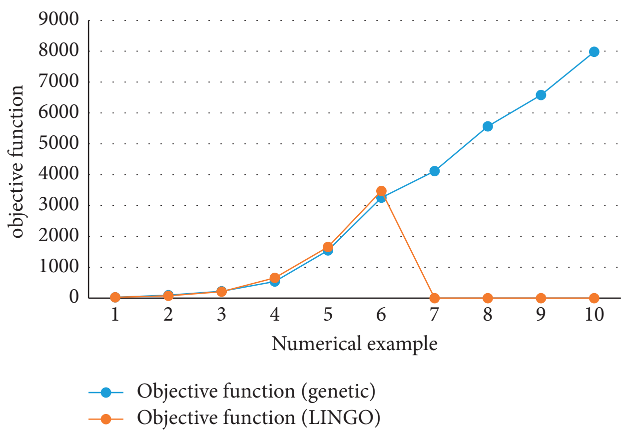

Figure 1: Change in the objective function in the genetic and LINGO methods with an increasing dimension of the problem.

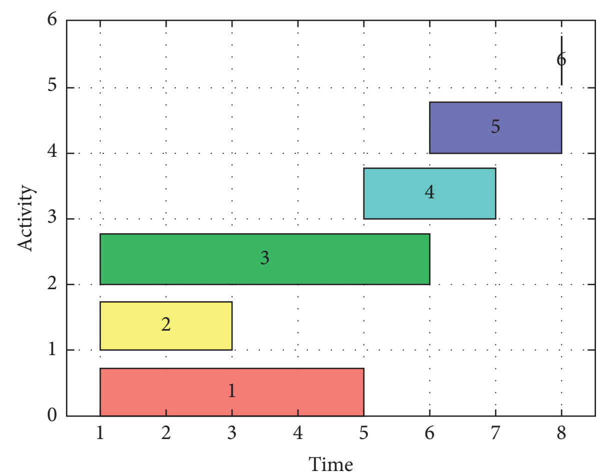

Figure 2: Display of the scheduling of activities with six activities in the genetic method.

Figure 2 shows how to schedule project activities. This figure is related to numerical problem 3 with six activities. Activity 1 lasted four working days, activity 2 lasted two working days, activity 3 lasted five working days, activities 4 and 5 lasted two working days, and activity six did not require considerable time and was completed on the eighth day. This scheduling is performed according to the amount of renewable and nonrenewable resources available.

Figure 3 is the amount of optimization of the final objective function in each iteration of the genetic algorithm. By performing each iteration of the algorithm, an attempt is made to optimize the value of the objective function, and in the last iteration, i.e., iteration 50, the optimal value of the objective function obtained from the genetic algorithm is obtained.

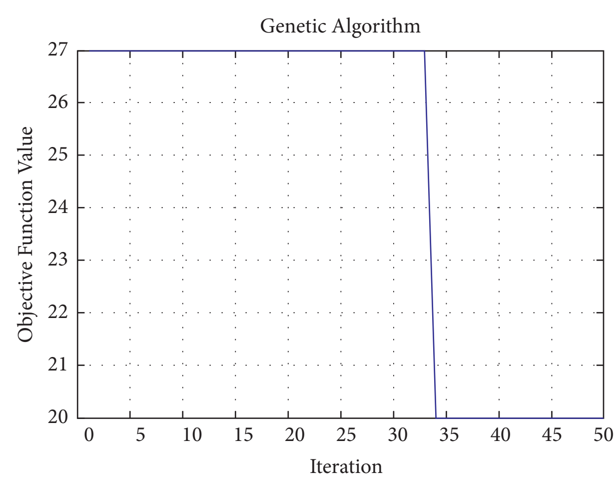

Figure 3: Optimality of the objective function by increasing the number of iterations in the genetic method.

After providing the results of problem-solving in LINGO software and the genetic approach to validate and test the proposed model, we analyze the numerical sensitivity. In this way, by changing each of the parameters of the lower limit of the renewable source, we analyze the cost of each unit of the renewable resource, the cost of each unit of the nonrenewable resource, and the model behavior and amount of change in objective function using the genetic metaheuristic approach.

Figure 4 shows that the amount of network costs increases with increasing the lower limit of the renewable resource. By changing this parameter from 4 to 10, objective functions increase constantly. When this value increases to 12, the amount of costs increases at a higher rate.

Figure 5 shows that the amount of network costs increases as the unit cost of the renewable source increases. By

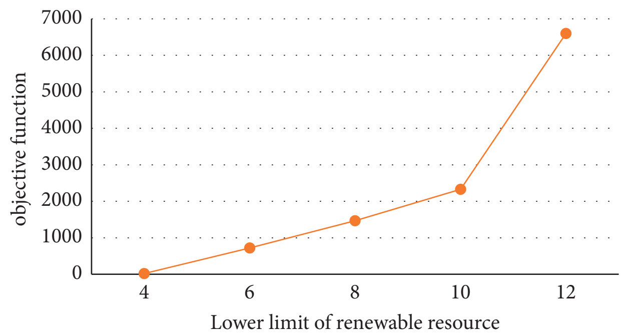

FIGURE 4: The amount of change in the objective function by increasing the lower limit of the renewable resource.

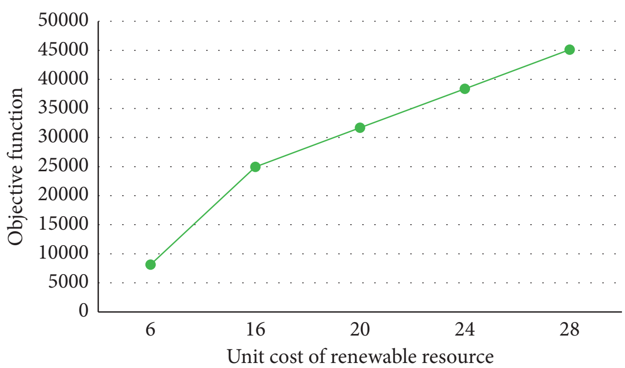

FIGURE 5: Amount of change in the objective function with an increasing unit cost of the renewable resource.

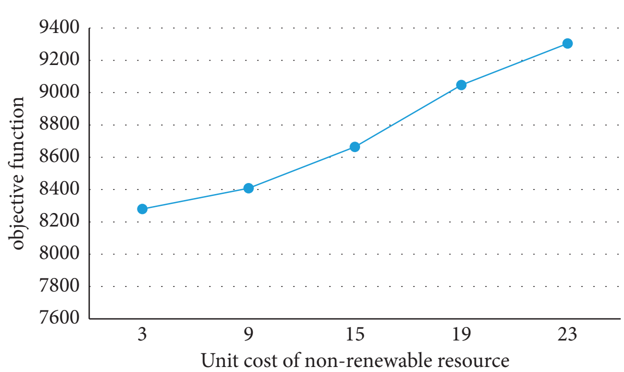

FIGURE 6: Amount of change in the objective function by increasing the unit cost of the nonrenewable resource.

changing this parameter from 6 to 16, the objective function increases with a constant trend. When this value increases from 16 to 28, the amount of costs increases at a lower rate.

Figure 6 shows that network costs increase as the unit cost of the nonrenewable resource increases. By changing this parameter from 3 to 23, the objective function increases with a constant trend.

Moreover, in the genetic metaheuristic approach, we examine the amount of change in the optimal objective function by increasing the number of iterations of the algorithm. It is clear that as the number of iterations of the algorithm increases, the value of the objective function or the cost of the scheduling problem improves. Figure 7 shows the amount of change in the objective function with an increasing number of iterations of the genetic algorithm.

FIGURE 7: The amount of change in the objective function with an increasing number of iterations of the genetic algorithm.

6. Conclusion

In this research, the resource-constrained project scheduling is raised; in addition to previous assumptions and models regarding scheduling, the reliability function is added to the mathematical model; and by investigating the probability of access to renewable resources, the project scheduling problem is investigated from a probabilistic point of view. The expressed problem planning model is a mixed nonlinear mathematical model that has been converted into a linear programming model using the properties of the exponential function. It should be noted that the use of this method for linearization of the model has been little investigated in the literature. Moreover, to solve the proposed problem, two exact methods in LINGO software and a genetic metaheuristic algorithm in MATLAB software are used to analyze the performance of both methods in solving the problem with different dimensions. After solving the problem, we concluded that in smaller dimensions, LINGO software leads to more optimal answers, while in medium and large dimensions, the genetic algorithm has shown better performance. In addition, from numerical example numbers 7 to 10, LINGO software has not solved the problem.

On the other hand, to validate the designed model, we performed numerical analysis of the parameters of the lower limit of the renewable resource, the cost of each unit of the renewable resource, and the cost of each unit of the nonrenewable resource and investigated the model behavior and amount of change in objective function using the genetic metaheuristic approach. It was inferred that with increasing all three mentioned parameters, the value of the objective function had an ascending trend. On the other hand, the amount of optimality of the target function was also analyzed by increasing the number of iterations of the genetic algorithm. It was observed that by increasing the number of iterations of the genetic algorithm, the value of the objective function becomes more optimal.

For future research in resource-constrained project scheduling, uncertain data in the problem can be used, and some parameters can be considered uncertain. Robust optimization, fuzzy planning, or probabilistic planning can also control uncertainty. In this way, the values of the objective function in certain and uncertain modes can be compared. Furthermore, more powerful metaheuristic algorithms such as gray wolf optimization or particle swarm optimization can be used in a resource-constrained project scheduling problem. The performance of different methods can be compared.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: The Nexus among Good E-Governance Practice, Decentralization, and Public Administration for Sustainable Local Development

Discrete Dynamics in Nature and Society

Received 31 October 2023; Accepted 31 October 2023; Published 1 November 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] W. Balisany, H. Özgit, and H. Rjoub, "The Nexus among Good E-Governance Practice, Decentralization, and Public Administration for Sustainable Local Development," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 9886372, 11 pages, 2022.

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Research Article

The Nexus among Good E-Governance Practice, Decentralization, and Public Administration for Sustainable Local Development

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The formulation and implementation of development-oriented public policies, particularly in a post-conflict state like Iraq, requires empirical investigation. Consequently, this study investigates the effect of effective e-governance practices and decentralization on public administration in the Erbil district of Iraq. The purpose of this study is to determine the role of decentralization as a mediator between good e-governance practices and public administration in relation to the sustainable local development of the Erbil city. The sample of 409 employees of the Erbil municipality who participated in the survey was analyzed using Partial Least Square Structural Equation Modeling (PLS-SEM) with the assistance of WarPLS 7.0. The results of the study revealed a significant correlation between e-governance practices and decentralization and public administration. In addition, it was discovered that decentralization has a significant effect on public administration. The finding of a significant negative relationship between e-governance and decentralization suggests that e-governance has a negative impact on decentralization in Erbil. The implications of the study are discussed, and the study suggests that devolving power and authority to subunits in Iraq would enhance public administration and promote sustainable local development.

1. Introduction

According to some studies, reestablishing electronic governance (e-governance) is the first step toward stabilization, reconstruction, and a significant transition to full socioeconomic recovery in a fragile and post-conflict state like Iraq [1, 2]. According to the literature, public administration, e-governance practices, and process participation contribute to sustainable development [3]. These are critical for the state's legitimacy, predicated on its ability to keep political promises and fulfill certain roles. According to Bala [3], "the mechanisms enacted at local levels and the administrators who comprise these systems are the channels through which policy becomes effective and through which the state's functions and services are allocated" (p. 594). As an ongoing case, the researcher has the opportunity for continuous observation and studies to understand whether e-governance practices and decentralization significantly impact local development or may not be sustainable in the long run. Currently, public administration and its departments operate in unstable and complex environments, owing to rapid advancements in knowledge and experience and the effects of economic, social, and cultural changes [4, 5]. This highlights the critical nature of adapting to these obstacles or setbacks. To overcome the obstacles posed by a lack of plans and developments in public affairs, high ability, sound e-governance practices, administrative decentralization, and managerial inventiveness are required to solve problems and achieve sustainable development.

Meanwhile, Brinkerhoff [6] asserts that each state must ensure the effectiveness of e-governance. Effective e-governance is defined as the process by which leaders focus their attention and direct it in the desired direction [7]; the success of public administration is largely dependent on a suitable and sufficient leadership style used by those reporting to him/her [5, 8]. While scholars and experts agree on the importance of good e-governance, personal leadership affects the capabilities of creative public officials. Leaders can help their employees develop their creativity by encouraging them to solve and address problems and then publicly present their solutions. According to El Meehy [4], despite Iraq's having symmetrical federalism since 2005, the state structure remains central. It is assumed that since 2013, authorities endorsed a plan aimed at decentralization reforms to create a functioning federalism [4]. Countries' need to have long-term development and stability [9–13].

This study aims to examine the process of rebuilding e-governance in Iraq, specifically in Erbil city, to shed light on the implications for the city's public administration as it moves toward development via decentralization. First, the research examines the direct consequences of e-governance practices and decentralization on public administration in a fragile post-conflict state such as Erbil. The purpose of this study is to determine the moderating and mediating effects of decentralization on the relationship between good e-governance practices and public administration in Erbil's sustainable local development. According to Grindle [14], "e-governance in developing countries should not aim for a comprehensive idealized vision of good governance, but rather for a limited set of changes sufficient to produce substantial improvements in political and administrative systems." Iraq's case study is informed by comparative examples from several other conflicts and post-conflict states as well as previous research on e-governance, decentralization, and public administration. According to Brinkerhoff and Johnson [1], "balanced attention to e-governance at the central and subnational levels may produce better results than a solely centralized approach" (p. 586). E-governance is defined by the OECD as "the application of modern information and communication technologies to the full spectrum of government functions" [15], (p. 3). E-government is organized in a more horizontal and transparent manner than conventional government. It facilitates the formation of new relationships within the public sector as well as between the government and individuals. It is anticipated that e-government will undermine traditional command and control structures while encouraging a more collaborative and decentralized decision-making style. Despite the significance of these concepts, prior research has been primarily theoretical, particularly in Iraq. As a result, this paper contributes to fill the gap in the literature by demonstrating how e-governance and decentralization can assist public administration in enhancing public services, achieving security, engaging citizens, and providing a mechanism for leadership selection in the pursuit of sustainable development (see Table 1).

2. Literature Review

2.1. Good E-Governance. "Governance" has been widely used in academic literature [20]. For instance, Awortwi [21] observed that it was frequently used in the literature on business studies to describe the relationship between companies' "micro-behaviors." Governance has been defined as "*the management of governments and public agencies and private organizations with a social mission*" [17, 22]. According to Awortwi [21], governance encompasses government activities; however, it also encompasses nonstate media through which some government policies are targeted and implemented. Additionally, Bawley [23] argued that civil society and the market are significant channels. The definition of governance has been a contentious issue [24], making it difficult to reach an agreement. It can mean various things to different people depending on their expertise. Nonetheless, Nadeem [17] observed that regardless of scholars' areas of expertise, the notion of the western concept of governance being globally applicable is assumed.

Information and communication technology are required for more efficient and transparent operations (ICTs). Electronic government, also known as e-government, is a new path forward in public administration that improves government operations in order to provide better information and services to the public by facilitating the engagement of various groups in governance, such as citizens and corporations, across society [25–27]. E-government is a new technique for most emerging nations to achieve economic improvement. This increases efficiency and transparency in the government and the general population [16]. E-government approaches like e-services, e-administration, and e-procurement have also been promoted to eliminate corruption and enhance public service delivery [28]. Srivastava [29] divided e-government research into three categories: e-government initiatives' growth and development; e-government acceptance and implementation; and e-government's influence on stakeholders.

2.2. Decentralization. El Meehy [4] defined "decentralization" as "a political process that restructures relationships between states, society, and the market, with significant implications for both civil society's role and state power." The term "conceptualization" evolved as some development stakeholders shifted their focus away from local public administration system reforms and toward enabling community-based and market-based stakeholders to participate in the formulation and implementation of policy. The World Bank [30] defines decentralization as "the process by which authority and responsibility for public functions are transferred from the central government to intermediate and local governments, quasi-independent government organizations, and the private sector." The United Nations' efforts, on the other hand, to advocate for decentralization, accountability, local empowerment, and responsiveness constituted significant reforms [4, 9]. Indeed, the UNDP [31] argued for a broad definition of "local governance" to

Table 1: Literature sources for the identification of research gap.

Author	Research focus
El Meehy [4]	Focused on the effect of a centralised structure
Al Khatab [9], Khalilzad and Pollack [10], Khedery [11], O'Driscoll [12], and Turan [13]	The need for long-term development and stability in central government
Al-Azar [16]	Efficiency and transparency in the government and the general population; therefore, the need for e-governance
Nadeem [17]	Concentration of authority and governance
Zafarullah and Huque [18]	Public administration and good governance
Nafe and Saeid [19]	Effectiveness of public administration accompanied by good governance, which must ensure equity protection, public welfare, and disclosure and transparency

emphasize the connection between democratic governance, civic value, and human development. According to the UNDP [31]; decentralization is "a collection of institutions, systems, and processes at the subnational level through which local governments interact with and provide services to citizens, groups, and local communities."

Nadeem [17] distinguished four types of decentralization: privatization, delegation and de-concentration of authority or administrative decentralization, fiscal decentralization, and devolution or democratic decentralization. Conyers [32] notes that some difficulties may arise as the government, aid agencies, and some academics advocate for decentralization. For example, some stakeholders may lose faith in the centralized government system if it fails to meet their expectations. Additionally, it may foster an impression that the system is unjust, unrepresentative, underperforming, and fails to provide equal opportunity. Decentralization is believed to be the "third wave" of democratization, as Huntington puts it [33]. The UNDP echoed this sentiment, arguing that "decentralization" is a critical component of "logic democratization" [32].

2.3. Public Administration. The scope of public administration is not universally defined [34]. Svara [34] asserts that "public administration is easier to explain than define." Additionally, several arguments have been made in the literature regarding whether or not public administration should be considered a study field [35]. According to Adam et al. [36], public administration is primarily concerned with governmental functions and enacting and interpreting laws and regulations. Thus, government programs are responsible for taxation, legislative activities, immigration services, foreign affairs, and national defense. According to the National Center for Education Statistics (NCES), public administration is "a program that prepares individuals to serve as managers in the executive branch of local, state, and federal government and focuses on the systematic study of executive organization and management." Nonetheless, some scholars define public administration as the implementation of public policy by policymakers, which establishes the competent authority to provide a solution to certain challenges and an organizational strategy for managing stakeholders [37–39]. The definitions of public administration imply that it is concerned with formulating and implementing public policies aimed at development.

2.4. Linking Good E-Governance, Decentralization, and Public Administration. Numerous studies have been conducted to examine the relationship between good e-governance and public administration on the one hand, and decentralization and public administration on the other. On the other hand, some findings have been inconclusive due to inconsistent findings. For example, Zafarullah and Huque [18] conducted research in Bangladesh on public administration and good governance. They argued that some small countries have relatively high expectations for monitoring a new path away from their country's traditions and the rigid public administration system they have conquered throughout their existence. Additionally, the study's findings indicated that certain factors, such as the legacy of Pakistani rules and procedures, harmed public administration progress in Bangladesh, and that post-reform efforts had no effect on fragmenting the administration's domination. Numerous factors resulted in the collapse of good governance as a result of the argument and dispute over the indicators, including the problem's poor presentation, high fraud rates, and a lack of administrative guidance and input. In addition, a number of internal and external factors exerted a great deal of pressure on the improving system, resulting in little progress in good governance. As a result, achieving good governance remains a distant dream without an effective and valuable tool for public administration.

Nevertheless, Nafe and Saeid [19] noted the absence of a system or model for evaluating the performance of municipal departments' public administration. However, Othman and Matarneh [40] demonstrate in their study that public administration can be effective when it is accompanied by good governance, which must ensure equity protection, public welfare, and disclosure and transparency. This view corroborates with Shah's [41] observation that ad hoc self-standing monitoring and assessment systems are more expensive and ineffective than a tool's built-in mechanism for government transparency, self-assessment, and citizen-based accountability. Additionally, Garcia-Sanches et al. [42] demonstrated that Spanish municipalities exhibit a high level of information transparency when it comes to environmental, economic, and social issues because they allow administrative proceedings to be conducted online and encourage citizens' active participation in and promotion of strategic, sustainable, and managerial issues.

For some time, the promotion of good governance in the delivery of public services and the role of decentralization have piqued the interest of policymakers and researchers

[35]. Decentralized governments, it is believed, will be closer to the populace and the people, and services will be more tailored to their specific needs. Meanwhile, Goel et al. [35] argue that decentralization can benefit or detrimentally affect public administration. On the plus side, decentralizing government functions will increase electoral control and competition between competing jurisdictions [43–47]. On the other hand, Adam et al. [36], Galiani et al. [48], and Reinikka and Svenson [49] assert that this results in a smaller economic scale for the provision of government services. Additionally, it increases the likelihood of a misalignment between the location of rewards for public services and political boundaries.

Additionally, Gonçalves [45] discovered that decentralization improved residents' access to public services and overall quality of life in Brazilian municipalities. Nevertheless, a similar study conducted in *Argentina* demonstrates the inequalities in service provision [48]. According to Reinikka and Svenson [49], inequalities arose due to decentralization of public resources, as some local elites appropriated public resources for their personal use. As a result, Olken [50] asserted that it restricts the reach of population monitoring initiatives.

The majority of the literature on the importance of decentralization has concentrated on fiscal decentralization [35, 36, 51, 52]. Nevertheless, limited studies examine alternative or few modes of decentralization [47, 53–55]. Meanwhile, the findings have been inconclusive and sensitive to the data and methodology used, resulting in inconclusive results.

Several studies have lately looked into the relationship between service delivery and e-government. For example, Singh et al. [56] conclude that e-government contributes positively and significantly in improving the public service delivery and administration, while also boosting fairness, efficiency, and effectiveness after conducting empirical studies in Fiji and Papua New Guinea. According to Bhuiyan [57], e-governance was crucial in modernizing Bangladesh's public administration to guarantee more efficient service delivery and the country's capacity to battle corruption and relieve poverty. García-Sánchez et al. [42] investigated the progress of e-government in 102 Spanish municipalities, both in aggregate and in each of Bwalya's three phases (2012). Despite this, the authors argue that Spanish legislation should monitor the evolution of local government e-administration to guarantee that it moves from one-way electronic involvement to two-way feedback and, eventually, to a public-private partnership [58].

A study by Bhuiyan [59], conducted in Kazakhstan, discovered that e-government provides benefits even with limited deployment. According to Bhuiyan's [57] study, the Kazakhstan's government must address a variety of operational challenges to improve service delivery that is more transparent, cost-effective, and accountable. The study identified several challenges, including a lack of qualified human resources, political support, and consensus regarding the management of digital divisions in public services, language barriers, and infrastructure development challenges. In a second study, Monga [60] revealed that e-government improved the quality of service delivery to citizens in India. This was done by making the government more open, reducing wait times for services, simplifying processes, getting rid of corruption, improving management, and changing the way public servants act.

In their study, Pan and Jang [61] examined the impact of the growth of e-government digital service delivery in the United States. The data suggest that e-government development goals, city population, and the council-manager form of government are all favorably related to service advancement, according to the researchers. Krishnan and Teo [62] investigated how governance impacts the development of information infrastructure and e-government using publicly accessible data from 178 countries. According to the research, political stability, government efficacy, and the rule of law, all aid the link between information infrastructure and e-government growth. On the other hand, voice and responsibility hurt the bond. Finally, Chatfield and Alhujran [25] investigated the efficiency with which 16 Arab nations' e-government websites and portals provide e-government services. Researchers contrasted the level of e-government in Arab countries to a few more developed nations (the United States, Denmark, Sweden, the UK, South Korea, and Australia). Most Arab nations are still in the early phases of e-government development, according to the survey, with information flowing just one way from the government to the people. The survey's results show that Arab countries are far behind the rest of the world when it comes to technology.

According to Asogwa, the aims include better access to government information, lower administrative expenses, improved openness among government entities, and reducing bribery and corruption (2013). However, a lack of bandwidth and Internet penetration, as well as a dearth of ICT infrastructure and personnel, frequent power outages, antiquated equipment, and other issues, make it impossible to harness and squander Nigeria's enormous potential. The expansion of e-government, according to Alaaraj and Ibrahim [63], has a favorable and substantial influence on good governance. E-services are important for excellent governance, but e-administration and e-procurement are not. In contrast, Naz [64] performed a study in Fiji to determine the function of e-government in improving service delivery and quality, as well as its impact on customer satisfaction. According to the paper, e-government has the potential to dramatically increase service quality and customer satisfaction. Previously, however, e-government research was restricted to developed countries alone [61, 62, 65]. Because of this, not much is known about how e-government works or how it affects service delivery in countries that are not as well off.

Furthermore, nothing is known about how the rise of e-government influences the relationship between decentralization and public service delivery in developing countries. Based on theoretical and empirical realities, we believe that successful e-governance initiatives and decentralization would increase efficiency in public administration and hence assure long-term local growth. Decentralization may also aid in the bridge between good governance and successful e-government. As a result, we propose the following hypotheses:

H1: Good e-governance practice has a positive relational effect on the public administration in Erbil Iraq

H2: Good e-governance practice has a positive relationship with decentralization

H3: Deccentralization has a positive relational effect on the public administration in Erbil Iraq

H4: Dcentralization partially mediates the relationship between good e-governance practice and public administration in Erbil Iraq

The conceptual model of this study as depicts the hypotheses is shown in Figure 1. The model shows the relational impact of good governance practice, decentralization in promoting public administration, and local development.

3. Method and Analysis

3.1. Data. This study uses a cross-sectional survey with a self-administered questionnaire to collect demographic data such as gender, age, experience, education, and employment department. The respondents were members of the Erbil municipality's staff. The Mayor was contacted to obtain permission from the staff to participate in the survey. The researcher was permitted to address the staff regarding the subject matter. Both the university and the municipality of Erbil sought and granted ethical approval. We invited all staff from various office units to participate, but we clarified that participation was voluntary.

Out of the five hundred and fifty questionnaires administered, only four hundred and nine were completed, representing about 74.36%. The demographic analysis reveals that most of the participants are from the finance department (27.8%), information technology (26.3%), and human resources (17.6%). In comparison, 13.9%, 8%, and 6.1% of the respondents are from the law, administrative, and other departments. Moreover, the majority of the respondents (60.2%) are within the ages of 51–60 years old, 61 years and above (19.5%), 45–50 years old (13.7%), 31–40 years old (4.1%), and 21–30 years old (1.7%). The gender analysis shows male participants are dominant (63.2%), while 36.3% are female. As for the educational background of the participants, the statistics reveal that majority are master degree holders (44.4%), bachelors (38.8%), PhD (10.7%), diploma (5.6%), and others (0.2%). Regarding the respondents' working experiences, 44.4% work between 6 and 10 years on their job, 38.4% worked for 11–15 years, while 11.2% had 16–20 years and above 21 years work experience, respectively. Also, as shown in Table 2, there is an absence of high collinearity among the variables. Decentralization, good e-governance, and public administration have a mean value of 3.93, 2.299, and 3.890, respectively, with a standard deviation below 1. This indicates a low variation in the items that measure each construct. Meanwhile, all the constructs were standardized before the path analysis [66].

This study uses preexisting questionnaire items and scales with minor modifications based on feedback from the supervisor and management during the pilot study. The measurement was conducted using a five-point Likert scale (1 indicating strong disagreement and 5 indicating strong agreement). The five dimensions of effective e-governance were accountability, transparency, participation, equality, the principle of justice, and the rule of law, with 29 items adapted and modified from previous studies [67, 68]. Decentralization was quantified using 18 items adapted from Rady [69]. Twelve items adapted from Dayanandan were used to assess public administration (2013).

3.2. Data Analysis. The WarpPLS 7.0 version was used to examine the model structure in this study [70]. WarpPLS is a partial least-squares regression approach for simultaneously assessing linear and nonlinear relationships [70]. According to Pavlou and Fygenson [71], "Partial Least Square Structural Equation Modeling" (PLS-SEM) is an excellent technique for analyzing big and intricate models that involve mediating or moderating effects. This allows for the modeling and testing of causal relationships across constructs as well as the testing of predictions that reflect real-world complexity. According to Urbach and Ahlemann [72], PLS-SEM is particularly useful when dealing with small samples since it is not dependent on data normality and may be used to model reflective and formative characteristics.

3.3. Assessment of Results of the Measurement Model. Table 3 demonstrates that all items have adequate loading (>0.50), Cronbach's alpha (>0.70), composite reliability (>0.70), and average variance extracted (>0.50) of all constructs are all over the minimal criterion, indicating good internal consistency. Furthermore, the discriminant validity evaluation findings shown in Table 3 support Fornell and Larcker's [73] finding that the square root of average variance retrieved in the diagonal of each construct must be bigger than the correlations between that construct and others. Meanwhile, the Fornell-Larcker criteria were supplemented by a new criterion (heterotrait-monotrait ratio) for measuring discriminant validity [74]. The HTMT ratio (0.9) is satisfactory, indicating that the constructs are discriminately valid. Also, the average total variance inflation for each variable is within acceptable limits, which shows that the constructs do not overlap (see Table 3).

4. Results of Hypothesis Testing

The study framework that depicts the hypotheses tested are shown in Figure 2 with the relevant expected path coefficients. The model fit indices show the data fitness with the following indices: "Average path coefficient (APC)" = 0.201, $P < 0.001$; "Average R-squared (ARS)" = 0.090, $P = 0.016$; "Average block VIF (AVIF)" = 1.068, (ideally ≤3.3); "Average full collinearity (AFVIF)" = 1.027, (ideally ≤3.3); "Tenenhaus goodness of fit (GOF)" = 0.207 (medium ≥0.25); "Simpson's paradox ration (SPR)" = 1.000 (ideally 1); "R-squared contribution ration (RSCR) = 1.000 (ideally 1); "Statistical suppression ration (SSR)" = 1.000 (acceptable if ≥0.7); "Non-linear bivariate causality direction ratio

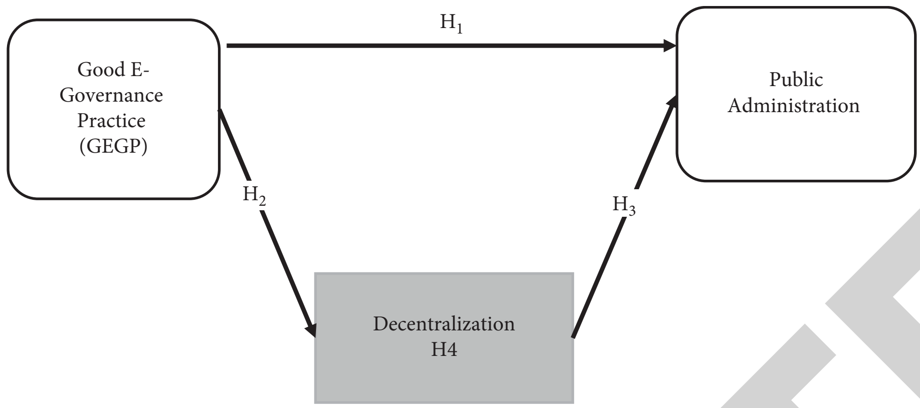

Figure 1: Conceptual framework.

Table 2: Mean, standard deviation, and correlations among the constructs.

Construct	Mean	Std. Deviation	1	2
1. Decentralization	3.93	0.585		
2. Good E-governance	2.299	0.930	−0.035	
3. Public adminsitration	3.890	0.557	0.240**	−0.083

**Correlation is significant at the 0.01 level (2-tailed).

(NLBCDR)" = 1.000 (acceptable if ≥0.7), and SRMR = 0.078 (Ideally ≤0.08).

The hypotheses' testing are presented in Table 4. The study revealed that good e-governance practices have a significant negative relationship with public administration (−0.323, $P < 0.001$). These findings imply that a change in the e-governance practice reduces public administration in Erbil. Therefore, H1 is supported and concludes that e-governance significantly impacts public administration. The second hypothesis was to test the relationship between e-governance and decentralization. As presented in Table 5, the result indicates a significant negative relationship between e-governance and decentralization (−0.086, $P = 0.039$). Thus, H2 is accepted and concludes that e-governance negatively influences decentralization in Erbil.

Moreover, the relationship between decentralization and public administration was tested in H3. The result shows a significant positive relationship between decentralization and public administration (0.192, $P = 0.001$). Therefore, H3 is supported and we conclude that decentralization of e-governance in Erbil significantly impacts public administration in the region. Meanwhile, the H4 formulated to investigate the mediating role of decentralization in the relationship between good e-governance, and public administration failed to show a significant result (0.017, $P = 0.317$). Therefore, we failed to accept H4 and conclude that decentralization does not mediate the relationship between good e-governance and public administration in Erbil.

5. Discussion

This study aimed to add to the body of knowledge on e-governance and public administration by examining the relationship between effective e-governance practices, decentralization, and public administration in Erbil, Iraq, to ensure local development. Earlier research examined the causes and consequences of effective e-governance. Nevertheless, some have demonstrated a link between e-governance and public administration. However, prior research on decentralization's role in public administration has been inconsistent and inconclusive. Our model demonstrates a variation of approximately 17% in explaining e-governance and decentralization as determinants of effective publication administration capable of adequately responding to the populace's yearnings for public service delivery.

According to our research, e-governance has a significant negative impact on the public administration in Erbil. These results confirm the findings of Zafarullah and Huque [18], who conducted a similar study in Pakistan and concluded that a variety of local factors may explain why governance has a negligible effect on public administration. Similarly, Iraq, which is currently in a post-conflict state, could be in a similar situation, which could explain the negative effect observed in this study. The finding, however, contradicts a number of earlier studies that discovered a significant positive relationship between e-governance and public administration and concluded that citizen participation would promote sustainable development [40, 41, 58]. Examining the relationship between effective e-governance and decentralization yielded similar results. Some researchers believe that a successful e-government should enable decentralization, allowing authority to be delegated to a lower level so that the populace has easier access to it [4, 37].

In spite of these drawbacks, decentralization has a positive impact on public administration. However, Goel et al. [35] determined that the impact of decentralization on public administration could be either positive or negative. Consistent with the findings of several earlier studies, this study demonstrates that decentralization has a positive and significant impact on public administration [43–45, 47]. In contrast, our findings contradict previous research indicating that decentralization and public administration have significant negative effects. In addition, it concludes that decentralization occasionally permits elites to appropriate allocated resources for their own use [36, 48].

Table 3: Model measures' assessment.

Construct	Items	Loadings	CR	AVE	CA	FVIF
Good e-governance practice	GGi	0.591	0.969	0.522	0.966	1.010
	GG2	0.588				
	GG3	0.627				
	GG4	0.621				
	GG5	0.582				
	GG6	0.546				
	GG7	0.779				
	GG8	0.749				
	GG9	0.778				
	GG10	0.728				
	GG11	0.774				
	GG12	0.786				
	GG13	0.831				
	GG14	0.772				
	GG15	0.554				
	GG16	0.810				
	GG17	0.763				
	GG18	0.711				
	GG19	0.746				
	GG20	0.690				
	GG21	0.779				
	GG22	0.641				
	GG23	0.717				
	GG24	0.769				
	GG25	0.768				
	GG26	0.785				
	GG27	0.795				
	GG28	0.777				
	GG29	0.762				
Public administration	PUB1	0.599	0.868	0.501	0.829	1.038
	PUB2	0.694				
	PUB3	0.692				
	PUB4	0.693				
	PUB5	0.653				
	PUB6	0.634				
	PUB7	0.614				
	PUB8	0.676				
	PUB9	0.597				
Decentralization	DEC1	0.540	0.935	0.778	0.925	1.033
	DEC2	0.624				
	DEC3	0.654				
	DEC4	0.752				
	DEC5	0.659				
	DEC6	0.749				
	DEC7	0.773				
	DEC8	0.747				
	DEC9	0.793				
	DEC10	0.763				
	DEC11	0.753				
	DEC12	0.815				
	DEC13	0.544				
	DEC14	0.554				
	DEC15	0.647				
	DEC16	0.596				

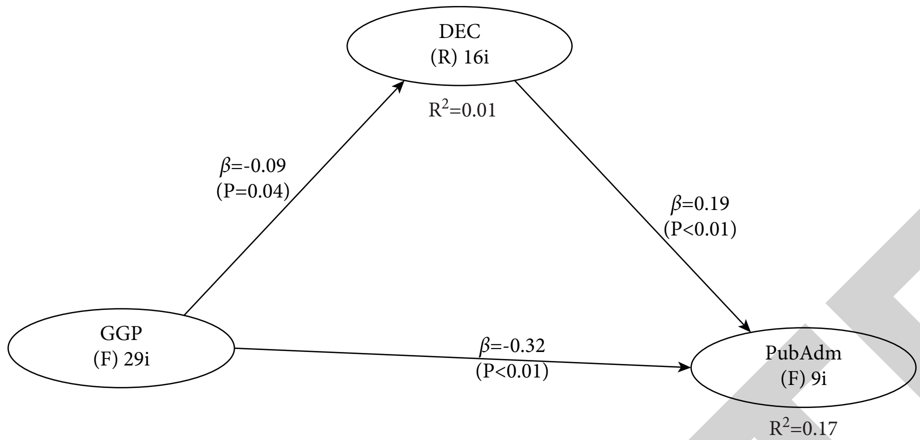

Figure 2: Model testing results.

Table 4: Discriminant validity.

	Fornell-larcker criterion			Heterotrait-monotrait ratio		
Constructs	E-gov	Decen	PubAdmin	E-gov	Decen	PubAdmin
E-gov	0.723					
Decen	−0.055	0.691		0.099		
PubAdmin	−0.088	0.174	0.651	0.145	0.223	

Square roots of average variance extracted (AVEs) shown on diagonal.

Table 5: Model testing.

	Hypothesis	Path coefficient	*P* value	Decision
HI	E-gov ⟶ PubAdmin	−0.323	0.001	Supported
H2	E-gov ⟶ decen	−0.086	0.039	Supported
H3	Decen ⟶ PubAdmin	0.192	0.001	Supported
H4	E-gov ⟶ decen ⟶ PubAdmin	0.017	0.317	No mediation

6. Conclusion and Recommendations

The purpose of this study was to determine the role of decentralization as a mediator between good e-governance practices and public administration in Erbil's sustainable local development. E-governance has forged a solid connection between decentralization and public administration. However, its implementation discourages public administration and may jeopardize local development, jeopardizing the sustainable development of the nation as a whole. Thus, stakeholders should modify their strategies and ensure that an effective e-governance model is effectively implemented. Study results revealed that decentralization has a substantial effect on government administration. Therefore, following remarks are crucial to be taken into account:

(i) It should not be oversold as a policy prescription for public administration, as it may breed corruption, especially in a developing nation like Iraq.

(ii) As the roles and responsibilities of central authorities in public services become more complex, as do the challenges they face in public services; it is imperative that information channels and decision-making authority be delegated to subunits.

(iii) In consideration of the needs of local communities, the central government must carry out these responsibilities in a fair and wholesome manner via efficient e-governance and decentralization. Thus, it aligns with the European Union's perspective, which seeks efficiency, transparency, accountability, and increased democracy in the delivery of public services, and highlights the parallelism between e-governance and decentralization in the delivery of public services values [13] are significant drivers for good governance.

As mentioned previously, e-governance is the first step toward stabilization, reconstruction, and a significant transition to complete socioeconomic recovery in a fragile and post-conflict state such as Iraq, and it helps to create opportunities for sustainable development. Hence, the challenges posed by a lack of plans and developments in public affairs, high ability, sound e-governance practices, administrative decentralization, and managerial ingenuity must be overcome in order to achieve sustainable development and create solutions for the existing problems. As a result, for the sake of good governance, public administrators should allow their employees develop their innovativeness by empowering them to solve and address problems and then present their remedies publicly.

This study is limited to the Erbil district in the Kurdistan region of Iraq. Nonetheless, it provides context for the post-conflict status of Iraq. Additional research must be conducted in other regions of Iraq to better comprehend Iraq's e-governance and public administration for sustainable development. Finally, it would be beneficial to compare Iraq to other nations experiencing similar conditions.

Data Availability

The data used to support the findings of this study are available upon reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Application of Sustainable Education Innovation in the Integrated Teaching of Theory and Practice Adopted in the Auto Chassis Course

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With the swift advancement of the auto repair industry, the demand for relevant talents and professionals in auto repair is thereby increasing steadily. Meanwhile, due to higher and higher expectations and requirements from contemporary society towards these professionals, it is a must to continuously reform the course teaching mode adopted for the auto repair specialists in the secondary vocational schools to adapt to the market needs ultimately. The study's primary aim was to investigate the application of sustainable education innovation in the integrated teaching of theory and practice adopted in the auto chassis course. Some research tools such as fuzzy Delphi method, fuzzy failure mode and effect analysis (FFMEA), and theory of inventive problem-solving (TRIZ) have been employed during the research process. After surveying and collecting the security incidents, which occurred in the integrated teaching of theory and practice adopted in the automobile chassis course, the presented reality that teachers were reluctant to accept the integrated teaching of theory and practice, and the deficiencies sensed in the school-enterprise engagement; the researcher firstly obtained the risk priority number (RPN) of each deficiency above via fuzzy failure mode and effect analysis (FFMEA) and accordingly expounded how TRIZ was applied under this circumstance. Furthermore, the conflicts among the enterprise, school, teachers, and students were explored in sequence utilizing technical contradiction solutions. Henceforth, three strategies were generated and proposed aimed at enhancing the integrated course teaching of theory and practice for the automobile chassis major: (1) hardware construction, involving the construction of not only the teaching workplace and teaching equipment but also teaching faculty training; (2) resource construction, along with the construction of school-based courses; and (3) improvement of classroom teaching. At the last stage, the three advancement strategies' validity was verified based on the implementation of a six-month remedial period.

1. Introduction

Due to the rapid advancement of the auto manufacturing process and technology and the growing high-tech application in modern automobile design, higher and stricter requirements have been cast on practitioners in the concerned areas, especially those engaged in vehicle body and chassis maintenance. Meanwhile, major shifts have also emerged concerning automobile maintenance's concept, methods, tools, and contents. Faced with the ceaseless improvement in both the social economy of China and the technology applied in this nation's auto repair industry, these secondary vocational schools of auto repair are pressured to update their concept of talent training, during which the concept of cultivating innovative technical talents must be highlighted [1, 2]. Besides, equal attention needs to be paid in the cultivating process to both operational and mental skills. In this case, students majoring in auto chassis maintenance are required to integrate theory and technology into practical maintenance operations as soon as possible and shorten the breaking-in period in line with their industry as best as possible [3, 4].

In recent years, the technology adopted in auto manufacturing has been experiencing an unceasing renewal alongside the perpetual update of newly designed automotive products and the fast-changing automotive technology. As the comprehensive chassis control system is advancing to more integrated, intelligent, and networked, greater and greater requirements are expected towards the chassis maintenance level. In this case, the original teaching model has landed into a predicament where it fails to adapt to the current teaching content and teaching methods. Hence, a series of drawbacks have come forth due to the monotonous teaching model where practical training teachers are responsible for the expertise operation and demonstration [5–7]. The first drawback lies in that these teachers find it almost impossible to take into account each student's need, thus making it rather difficult for all students to observe and hear clearly. Secondly, for secondary vocational students whose academic performance tends to be not so satisfying, they would feel considerably tough to master the knowledge and skills with merely one single operation demonstrated by a teacher; thus, it is not uncommon for students to make errors frequently when practicing converting the textual knowledge into practical operation. Thirdly, a high damage ratio of equipment has resulted from the lack of procedural guidance. Last but not least, book-centered teaching bias infiltrates as novel technologies could not be introduced into the conventional course teaching in a spontaneous way [8–10].

Nevertheless, the reality should never be neglected that a relatively high requirement is claimed during the practical training process with regard to the specialty of automobile application and maintenance. Amid the construction of chassis maintenance projection, an enormous investment is a precondition in purchasing and installing relevant equipment for practical training [11–13]. At the initial stage, where a series of chassis maintenance equipment such as balancing engines, tire changers, and lifting machines are essential, not only is enough space needed, but also the rest expenses are shockingly huge, not to mention the cost of related consumables in the subsequent process of practical training. It is rather challenging for secondary vocational schools, whose sufficient funding sources are normally impossible to guarantee, to cultivate qualified talents in auto chassis maintenance through the traditional training model [14–16]. To get out of the predicament, the existing practical training environment needs updating and optimizing by exploring the most suitable educational and skill training approaches based on corresponding research of the teaching characteristics manifested in auto chassis maintenance projection. Under the circumstance where the actual investment in the training environment fails to match the professional standard, the integrated research, established on both the projection's characteristics and the existing training environment, is considered the only route, on the one hand, to reform the current curriculum and, on the other, to enhance the impact of teaching and training [17, 18] significantly.

Concerning the resource system of teaching in chassis maintenance projection of auto repair, we, more often than not, simply focus on relevant courses' practical teaching resources, such as teaching venues, teaching tools, and teaching materials. However, preternaturally practical as the training projection is, its teaching resources are supposed to be "holographic," meaning that deeper exploration and broader expansion in an all-round way are urgently needed to ultimately construct a multidimensional system, such as the curriculum teaching system of information technology, the teaching system of cooperation with the auto industry, and the teaching system of coordination with professional training institutions of auto repair [5, 19]. Aside from exploring the abundant teaching resources, an appropriate combination with this course's teaching objectives is also imperative to grope for a rational mode of integration and expansion, including the organizational form, blending content, and assessment systems. To keep pace with the development trend, a growing number of secondary vocational schools in China have set about digging into an integrated teaching mode of theory and practice. To truly implement the integrated teaching mode into professional courses via the behavior-oriented approach, these organizations are committed to combining professional theoretical knowledge with operational skills, making full use of information technology, and developing serviceable courses that corresponding enterprises could adopt and to ameliorating their teaching venues. As far as the auto repair major of secondary vocational education is concerned, a feasible way of cultivating skilled talents is in dire need to ensure the gradual adaptation to the new curriculum reform and to the progress achieved in both the auto repair industry and the general society [11, 16]. Based on the research background and motivation above, the three key research tools, involving fuzzy Delphi method, fuzzy failure mode and effect analysis (FFMEA), and theory of inventive problem-solving (TRIZ), were utilized in this study. After surveying and collecting the security incidents, which emerged in the integrated teaching of theory and practice adopted in the automobile chassis course, the manifested reality that teachers were reluctant to accept the integrated teaching of theory and practice, and the deficiencies perceived in the school-enterprise engagement, the researcher obtained the risk priority number (RPN) of each deficiency above via fuzzy failure mode and effect analysis (fuzzy FMEA), followed by proposing correlated strategies about how to optimize the integrated teaching of theory and practice for the maintenance of vehicle body and chassis. Moreover, the validity of these optimizing strategies was verified based on the implementation of a six-month remedial period [7, 8, 12, 20, 21].

Overall, given fast progress of the auto repair industry, the demand for related talents and professionals in auto repair is growing constantly. Hence, this study intends to analyze and inspect the application of sustainable education innovation in the integrated teaching of theory and practice adopted in the auto chassis course. This study can contribute to reinforcing the integrated course teaching of theory and practice for the automobile chassis major.

2. Literature Review

Relevant literature is to be reviewed in this section, which has been split up into three parts, with the first part focusing on literature about the integrated teaching model of theory and practice, the second part addressing literature regarding the application of TRIZ in education innovation, and the last part probing into the related application contents of the fuzzy theory. The integrated teaching of theory and practice, which originated in Europe at the outset, has been expanding rather rapidly owing to the close attention and strong support from the local government. Having undergone long-term practice and being summarized, this teaching model has succeeded in evolving into a comparatively impeccable and practical teaching mode in vocational education. As for the "dual system" advocated in Germany, its training goal lies in that instead of systematically imparting theoretical knowledge to students, secondary vocational schools are supposed to undertake the prime mission of enabling their students to engage independently in various professional activities by imparting to student's compulsory theoretical knowledge and by providing with them practical professional training. Hence, part of the German scholars such as Walden [17], Putz [13], and Sondermann [16] attached more of their attention to "action-oriented" vocational education, which emphasizes the "key competence" and "students' comprehensive capability of independence," that is to say, students are requested to construct their own capacity system by "acquiring information, formulating plans, implementing plans, and evaluating plans all in an independent way." On the other side, this "dual system" of Germany functions almost as an embodiment of the integration of theory and practice at a relative macro-level. Meanwhile, it is not hidden that excessive reliance has been attached on enterprises in this "dual-system" model, which could lead to the marginalization of schools' role. When such "dual system" is being applied, it is the enterprises that grasp the decisive role during the integrated course teaching of theory and practice, while schools are reduced to a lower position of support. Obviously, this model is not applicable at all when it comes to the contemporary situation of the integrated teaching of theory and practice in China where school education serves as the mainstay and enterprises simply act as an assistant.

Vocational education in the United States, evolving from the vocational education concept of competency-based education (CBE), belongs to that type of model, which is "wide-range, professional, and multifunctional." For a long-lasting period, American scholars tend to fix their eyes on the investigation of the interactive integrated teaching model. Part of the scholars [8–10] are more focused on studying the integration of theory and practice from the perspective of practical teaching cases, and they opt to target these aspects as the core of practical teaching: further deepening the case teaching and strengthening students' ability to analyze and to solve problems. There are also scholars [9, 15, 18] who, after analyzing the integrated teaching from teachers' perspective, pointed out that teachers are expected to be adequately capable of combining the theoretical teaching with practical training, while at the same time trying to avoid lecturing alone for too long; moreover, sufficient attention is required in the cooperative discussion with students to address the specific problem. Regarding the teaching model of US vocational education, although more concerns are distributed to the development of teachers' quality, each teacher functions basically as a facilitator, reflecting the fact that this kind of vocational education emphasizes the subjectivity of its students, particularly the self-evaluation of students. Pitifully, this type of "self-training evaluation system" has not yet sought its hotbed in China since the entanglement of whether students should be delegated with the priority of instruction evaluation is still in suspense [4, 18].

Australia's competence-based education and training (CBET) is a state-supervised vocational education model under the market's regulation. All along a nice bit of focus has been cast on exploiting effective teaching tactics in Australia [3, 11]. In recent decades, quite a few local college scholars have attempted to carry out their research into integrated teaching strategies, primarily including thematic teaching method, interactive teaching mode, and role-playing teaching, all of which fully pertain to the integrated model associating the theory with practice. At vocational education colleges of Australia, textbooks are not set and employed in unified standards, but instead each teacher shoulders the task of selecting specific textbooks according to the actual need. Despite the great flexibility in the teaching procedure, it is rather challenging to supervise and monitor the teaching quality due to the absence of a standardized teaching basis (namely textbook). In parallel, students are facing the obstacle of lacking relatively reliable materials for self-study [12, 14].

Hereby, it can be asserted naturally that in-depth research on the integrated teaching of theory and practice has been conducted in developed countries such as Germany, the United States, and Australia, and at the same time, this type of teaching method has already been vigorously implemented in those nations. However, it is undisputed that each mature vocational education model, which has gone through constant evolution under its specific background and environment, needs to tune into various factors, involving its local economy, culture, demography, and education. In China, where few changes would be made concerning its school-based vocational education in the short term, it is unfeasible to delegate to students the right of assessing the teaching efficiency, and developing a series of unified teaching materials is requisite to cater for the form of class teaching. As a result, the allegation can be generated that the initiative of ponderously transplanting the integrated teaching model abroad into China is inconsistent with its domestic condition. To patch it up, opportune reference and absorption from foreign nations in a critical way are well worth a shot in the pursuit of the integrated teaching model, which best suits its both national and provincial conditions.

TRIZ, abbreviation in Russian of Teoriya Resheniya Izobretatelskikh Zadatch, means "inventive theory of problem-solving," which is to seek potential access to technological innovation in a systematic way. It is deemed as a powerful innovative tool as it depicts the trend of innovation through the evolutionary model of technological development. After an investigation into over 200,000 patents, it has been discovered via this tool that several ubiquitous basic problems and consistent solutions are commonly scattered among various innovative achievements in different fields [7, 13]. In other words, a single solution is applicable in addressing certain problems arising in different fields and at different times. In view of this case, the process of invention and innovation and the problem-solving strategies are recommended after systematically sorting out diverse problem models from these patents investigated. Regarding the implementation of TRIZ in educational innovation, the TRIZ innovation principle proposed by Chen et al. [1] who had summarized based on a large number of engineering technology patents is considered rather classic. The team led by Mann [8] directed a long-term survey systematically into how well the TRIZ innovation principle originally adopted in the area of engineering technology performed when it was used in the domain of business and management. On the basis of the initial TRIZ innovation principle, this team had collected and analyzed plenty of linked cases before putting forward in match with the business and management domain of the contradictory parameters, which in this team's firm belief could be used to define issues in that domain. Marsh et al. [9] and their partners probed into the conceptual issues that doctoral students encountered when seeking potential solutions in their learning curve, the first time ever for the contradiction matrix to be used to resolve education-related technical conflicts. They redefined the 31 business functions of the contradiction matrix, perfecting the matrix to be more in line with the developing trend of higher education. More importantly, Marsh et al. [9], together with their partners, connected the 40 innovative principles with the education domain and accordingly proposed another 40 innovative principles exclusive to the education domain. Each of the 40 principles newly proposed has been attached with corresponding explanations and real cases, which is definitely more conducive for other researchers not just in making further comparisons, but in deeply interpreting these 40 innovative principles in the education domain. In consequence, not only has the application sphere of the TRIZ theory been extended, but also vital prerequisites have been provided in the utilization of the TRIZ theory to tackle innovation obstacles in the area of education.

Regarding the application of fuzzy theory adopted in this research, Delphi method, a method of surveying experts' opinions and a group decision-making approach, has been established mainly to obtain the consensus among certain expert group and to acquire the consistent viewpoint towards a specific object. The Delphi method is extremely advantageous not only in collecting varying thoughts but also in taking into account the quality of an expert's independent judgment. It is Dawood et al. [7] who analyzed the fuzzy theory into the Delphi method with the aim of overcoming associative barriers annoyed when applying the traditional Delphi method in terms of the research time, cost, and ignorance of experts' opinions. In this untied approach, the geometric mean is treated as the basis of assessment in selecting group's decision-making to avoid the negative impact caused by extreme values, thus bettering the selecting effect of the assessment factor. The outcome generated via the fuzzy Delphi method is feasible to be input into FMEA for further discussion. FMEA was propounded by reliability engineers in 1950 during the failure analysis of the rocket system. When applied for failure analysis, it is called failure mode effect analysis (FMEA). Despite its superiority in uncomplicated principles and strong operability, there are high possibilities of occurring errors caused by robust personal subjectivity in the rating process of the risk factors such as occurrence (O), severity (S), and detection (D). In view of the defects that related theoretical support could be insufficient in the attempt of equivalently quantifying risks by multiplying O, S, and D to obtain RPN and that risks represented by the same PRN could be indistinguishable, a couple of scholars such as Pillay and Wang [11] and Yan et al. [3] suggested FMEA, which is based on evidence reasoning, and meanwhile simulated the diversity and uncertainty arising from the FMEA evaluating process for rating. This method enables experts in concerned area to evaluate risk factors with the conventional mode of digital rating. In conformity with fuzzy logic, Bowles and Peláez [2] described another way of prioritizing the risks generating in the failure mode in FMEA system, and fuzzy language was used to outline O, S, D, and the failure risk. The relationship between the failure risk and O, S, and D was demonstrated via the "if-then" fuzzy rule base developed out of experts' knowledge and experience. Since the result of risk assessment is illustrated in fuzzy language, accurate values can only be gained and later sorted after the fuzzy language has been defuzzified.

With the research objective of addressing the defects existing in the integrated teaching of theory and practice for the auto chassis major in China, FMEA has been picked in this study as the core framework, along with the application of both fuzzy Delphi and fuzzy inferences stemming from the fuzzy theory. After the key failure modes disclosed in the integrated teaching of theory and practice had been found in related courses for the vehicle chassis major in secondary vocational schools, viable solutions and optimizing tactics were suggested based on TRIZ and how well the effect of optimization presented was verified as well. Concerning the remaining sections of this research, Section 3 introduces the model constructing and solving; Section 4 outlines relevant cases and data analysis; and the summary is delivered in the last section.

3. Research Methodology

3.1. Problem Statement. This research was initiated in January 2020. At its first stage, expert questionnaires of fuzzy Delphi method were issued among 5 experts (a professor of auto repair specialty, 2 senior technicians of auto repair, and 2 senior lecturers from certain school, with the weight allocation of 0.3, 0.3, 0.2, 0.1, and 0.1), of whom the opinions of decision-making group had been anticipated. In this study, the auto repair major of a specific secondary vocational school located in Suzhou City of China was picked and surveyed to confirm the key failure mode's assessment factors lying in the integrated course teaching of theory and practice for auto chassis major. The research outcomes would be elucidated mainly from the following three segments: the first segment expounded on how to construct the fuzzy failure mode and the effect analysis; the second provided certain countermeasures based on TRIZ; and the third verified how these strategies had functioned in this school after half a year.

3.2. Development Process of the Integrated Course of Theory and Practice. According to the Notice on Printing and Distributing Technical Regulations of Developing Integrated Course issued in 2012 by the Ministry of Human Resources and Social Security of China, the concerned development process is mainly composed of the following six parts.

3.2.1. Completion of the Organic Integration of Multiple Courses. Instead of a mere addition of various course contents, the organic integration of distinct courses refers to the intact procedure where the whole knowledge needs to be reorganized and summarized before being finally integrated into pursuit of deeper logicality.

3.2.2. Compilation of Teaching Syllabus, Plans, and Materials Adaptive for Integrated Teaching. In view of the fact that the teaching syllabus and contents adopted in secondary vocational schools are limited solely to the segmented teaching model, it is nearly impossible for these teaching syllabus and contents to perform effectively in the integrated course teaching. Besides, the teaching materials currently used for the integrated teaching of "auto chassis" course are not impeccable yet. To better tackle this issue, it is highly advisable that secondary vocational colleges formulate their own teaching syllabus, respectively, and compile corresponding textbooks. There is no doubt that the teaching outcome would turn out to be fabulous if such type of textbooks came into use, which is compiled in conformity to students' personal learning situation, schools' talent training positioning, and the latest social requirement on students.

3.2.3. Cultivation of Dual-Qualified Teachers. For the aim of cultivating dual-qualified teachers, exclusive training opportunities are exceedingly recommended in secondary vocational schools for educators who are responsible for the integrated teaching of theory and practice in the "auto chassis" course to lift bit by bit their teaching ability in the training process. Meanwhile, ideological work prepared for these teachers could never be ignored for the sake of their perfection in teaching expertise. Furthermore, young teachers are able to visit and learn about a specific enterprise by taking advantage of the school-enterprise cooperation. In this way, this group of teachers would, on one hand, be awarded the wonderful chance of strengthening their individual practical ability and, on the other, gain a more comprehensive understanding of their students' present learning situation, thus playing a satisfying role in comprehending relevant requirements asserted in job descriptions towards potential job hunters. Likewise, it is absolutely facilitating if schools are able to invite professional talents dispatched from enterprises to give certain extracurricular tutoring among the students, or to offer forums at campus to grab students' attention.

3.2.4. Classroom Construction for Integrated Teaching of Theory and Practice. The construction of classrooms prepared for the integrated teaching of theory and practice is, to high extent, no picnic for many schools as these schools are commonly in lack of not just sufficient funds but also suitable precedents to imitate. In view of this embarrassing situation, vocational schools, in quest of support in financial funds and training venues, are advised to strengthen their interaction with the local government to cope with the financial matter and the restricted area. While in the purchase of relevant multimedia equipment, factors such as the cost and practicality of these items must be thoroughly considered; otherwise, the integrated teaching tends to face the adversity of being doomed a failure. In these classrooms prepared for the integrated teaching, specialized training stations, full set of training and measuring tools, and sufficient training equipment are indispensable, so is the teaching model of an intact vehicle.

3.2.5. Reinforcement of Practical Training Management. It is not strange at all that practical training has been ignored unconsciously in numerous schools when conducting the integrated teaching model due to the conventional thinking pattern entrenched solidly in China's education, to which constant and intensive attention needs to be paid in the upcoming implementation of the integrated teaching of theory and practice in the "auto chassis" course. An intact teaching system aimed at schools' practice teaching deserves to be formulated; hereby, each of the teaching staff and every student could be pressured to comply with it. At the same time, scrupulous maintenance of these classrooms reserved for the integrated teaching ought to be strengthened, and any illegal operation must be forbidden during the learning process among all the users, whether it is a student or a trainer; otherwise, it is on the cards that the teaching facilities might be damaged or out of order.

3.2.6. Delegation of the Teaching Assessment System to Students. The teaching assessment system must be delegated to students considering the ubiquitous situation where a mass of teachers tend to think highly of the teaching outcomes they have achieved, but pitifully enough fail to receive satisfactory assessment results in the end, for which lack of related experience in the integrated course teaching of "auto chassis" commonly existing in China should be blamed. On the contrary, once the teaching assessment system is delegated to students, they are enabled to elaborate whatever they think about, including their expectations on teachers' teaching attitude, teaching pattern, and methods.

3.3. Establishment of Assessment Criteria via the Fuzzy Delphi Method for the Integrated Course Teaching of Theory and Practice. Through relevant literature review and several expert interviews, the failure assessment mode of the integrated teaching system of theory and practice in auto chassis has taken its preliminary framework, functioning as the devising basis for the fuzzy Delphi method questionnaire and as the selecting foundation for the assessment criteria to further facilitate the subsequent steps. To block these biases caused by personals' subjective consciousness, the fuzzy Delphi method proposed by Klir and Folger [6] is introduced, of which differing opinions offered within the project team are incorporated by processing the geometric mean as the intermediate value of the triangular fuzzy number. In this way, the key factors tend to be evaluated more in line with the real situation. Saaty [15] asserted that more accurate outcomes could be captured by representing experts' consensus of decision-making with the geometric average in disposing the generalization of averages. In virtue of these scholars' proposals, the geometric mean would be deployed in this research as the intermediate value of the triangular fuzzy number. Prior to defuzzifying the fuzzy set via the fuzzy theory for the sake of a faultless weighted value of fuzzy risk, a fuzzy set is the major premise needed to form concerning the severity, occurrence, and undetectability of each factor originating from the project's team members in the means of fuzzy Delphi method, and subsequently, it comes the judging section, which proceeds according to the following steps:

(1) a_{ij} is set as expert i's opinion towards failure cause j. Firstly, a triangular fuzzy number $A_{ij} = (l_{ij}, m_{ij}, u_{ij})_{L-R}$ is ascertained, which contains all the opinions of expert i towards failure cause j, and among which, $m_{ij} = (a_{1j} \times a_{2j} \times \cdots \times a_{nj})^{1/n}$ and $u_{ij} = \max(a_{1j}, a_{2j}, \ldots, a_{nj})$, $i = 1, \ldots, n$.

(2) The fuzzy relationship matrix W of the entire evaluations from expert i towards failure cause j is established. $W = (w_1, w_2, \ldots, w_j)$.

$$w_j = \left(l_{ij}, m_{ij}, u_{ij}\right)_{L-R}, i = 1, \cdots, n, \quad j = 1, \cdots, r. \tag{1}$$

(3) The fuzzy off-bar matrix obtained is converted into a single value through the method of average.

$$O_j = \frac{\left[\left(u_j - l_j\right) + \left(m_j - l_j\right)\right]}{3} + l_j, \quad j = 1, \cdots, r. \tag{2}$$

(4) Eventually, the evaluation set of the severity and the undetectability of all these failure causes after defuzzifying the fuzzy set via the fuzzy theory are gained, which is followed by the conversion into a crisp value.

3.4. Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). Failure mode and effect analysis (FMEA), an analysis technique that identifies the failure mode of a potential product, is universally used for the purpose of detecting failures, which might lead to further accidents or detrimental events. The conduction of FMEA is routinely completed at the early stage of a product's life cycle so that this product's safety and quality can be enhanced and that its risks and costs of development will be weakened, thus ultimately helping lift the corporate image and competitiveness in addition to the customer satisfaction. Typically, FMEA is used roughly for three purposes: design, process, and service, also named DFMEA, PFMEA, and SFMEA separately. The model deployed in this study is SFMEA, namely FMEA for service. At the early planning stage of the service system, the potential missing mode of each process, along with its degree of impact, has been explored before the severity (S), occurrence (O), and detectability (D) of each failure mode are unearthed. Next, diverse workable methods are expected to seek in order to avert or mitigate the occurrence and the negative impact of that service failure mode for the eventual sake of the refinement of the system structure's verification competence. In this way, planning of the system structure could be ameliorated before the service system is officially put into operation, so that the failure mode of service could be neatly avoided and consequently there comes gratifying elevation in the service quality [5].

A detailed analysis of the failure mode has already been delivered in the traditional edition of FMEA, along with a summary of these factors linked with the failure factors. In that traditional edition, risk priority number (RPN) has been adopted to measure the three key parameters, including severity (S), difficulty of detecting (D), and occurrence (O), on a scale of 1 to 10 points, and lastly, the risk priority number can be figured out by multiplying these three parameters. Undeniably, there may be subjective bias of opinions during the assessing process where the entire qualitative opinions are appraised in a quantitative way. Regarding each project with a higher risk priority number, the optimization measures recommended shall be taken first to fence the system against any risks. To overcome these shortcomings, the steps of constructing the fuzzy risk priority number (FRPN) model [11] adopted in this study are outlined as follows:

(1) The semantic variables and the membership function of fuzzy risk are constructed: firstly the entire measuring criteria of occurrence and difficulty of detecting and severity set in the FMEA table are combined, and a fuzzy set diagram of fuzzy risk is drawn. Every variable is feasible to be described through verbal ratings: {*FL* (fairly low), *L* (low), *M* (medium), *H* (high), *FH* (fairly high)}. In reference to the definition of FMEA commonly used in the service industry [10], a relational diagram between verbal ratings and membership functions has been offered, with the rating standards of these verbal ratings interpreted at length in Table 1 (Figure 1).

(2) Assume that a total of n experts judge whether a specific failure mode "$x \in A$" is "true" or "false," in which $x \in X$, and A refers to the fuzzy set of X. $a_i(x)$ is used to represent the judgment of expert $i(i = 1, \ldots, n)$ on this failure mode: when $a_i(x) = 1$, it means that expert i judges this failure mode to be true, while $a_i(x) = 0$, it signifies that expert i estimates that mode to be false. When $A(x) = 1$, $x \in A$; $A(x) = 0$, then $x \notin A$, but if $A(x) \in (0, 1)$, x is

Table 1: Verbal rating interpretation of each linguistic variable.

Verbal rating	Linguistic variable O	Linguistic variable S	Linguistic variable D	Triangular fuzzy value
VL (very low)	Extremely rare occurrence of failure mode	The teachers are willing to adopt the integrated teaching of theory and practice with a normal teaching model despite this factor	Almost definitely could this factor be spotted prior to the teaching arrangement	(0, 0.15, 0.3)
L (low)	Possibly once, but no more again	The teachers are still willing to adopt the integrated teaching of theory and practice but with some resistance penetrated in teaching due to this factor	Highly likely would this factor be spotted prior to the teaching arrangement	(0.2, 0.35, 0.5)
M (medium)	Possible for once more	The teachers are not averse to the integrated teaching of theory, but restricted by this factor, smooth teaching cannot be guaranteed	Half as likely could this factor be spotted prior to the teaching arrangement	(0.4, 0.6, 0.8)
H (high)	Basically at least once	Part of the teachers are averse to the integrated teaching of theory due to this factor and unwilling to adopt it in class	Rarely could this factor be spotted prior to the teaching arrangement	(0.7, 0.85, 1.0)
VH (very high)	Basically several times of occurrence	The majority of the teachers are allergic to the integrated teaching of theory due to this factor and unwilling to adopt it in class	Almost possible could this factor be spotted prior to the teaching arrangement	(0.9, 1.0, 1.0)

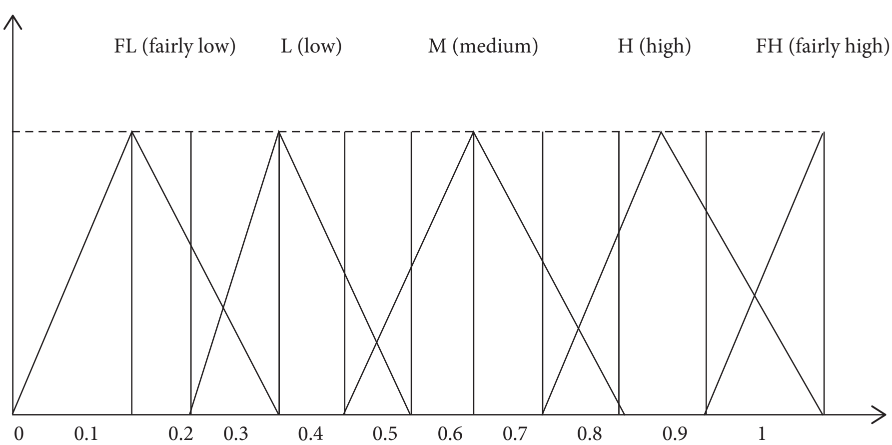

Figure 1: Membership function of verbal ratings.

deemed as part of A. When an expert shows any variance in his/her personal domain knowledge and professional experience, $A(x) = \sum_{i=1}^{n} C_i a_i(x)$ will be regarded as the membership function of element x towards the set A. C_i indicates the weight value assigned according to the domain and experience of expert i, and right here, $\sum_{i=1}^{n} C_i = 1$.

(3) A semantic rule base is established: the grammatical form "if-then" is most widely adopted in the methods and procedures of establishing a rule base, namely a genre of rule based on which an expert's knowledge is rewritten using the "if-then" form after having garnered his/her knowledge and the operator's working experience. With the aim of building a fuzzy rule base, experts need to classify various assemblies of verbal ratings regarding the linguistic variables O, S, and D and later depict them through an assembly of verbal ratings with risk priority, thereby reflecting the risk priority of each rating assembly of O, S, and D, respectively. A total of 5 verbal ratings are set up for each linguistic variable of O, S, and D, so there are 125 ($5 * 5 * 5 = 125$) assemblies of verbal ratings in sum; that is, the total number of fuzzy inference rules is 125. Considering the fact that there are a couple of verbal rating assemblies sharing the same risk priority among those 125 rules acquired, repeated trials and reductions are needed to eventually obtain the functional fuzzy rule base.

(4) The fuzzy theory is examined: as for the input of the fuzzy logic inference, it can be either an explicit value or a fuzzy set, while the output must be a fuzzy set. In this way, a conclusion's degree of membership should be set as "degree of truth," followed by ranking each risk priority number and every failure mode, and finally defuzzifying these values in order for an explicit outcome. Supposing that n sorts of verbal rating assemblies are attained in pursuit of verbal ratings of risk priority in the process of integrating the verbal rating assemblies of each failure

Table 2: 40 inventive principles for education (Marsh et al. [9]).

(1) Segmentation	(2) Taking out (extraction)	(3) Local quality	(4) Asymmetry	(5) Merging (combining)
(6) Universality	(7) Nested doll (matryoshka)	(8) Anti-weight (counterweight)	(9) Preliminary anti-action	(10) Preliminary action
(11) Beforehand cushioning	(12) Equipotentiality	(13) Inversion	(14) Curvature	(15) Dynamics
(16) Partial or excessive actions	(17) Another dimension	(18) Mechanical vibration	(19) Periodic action	(20) Continuity of useful action
(21) Rushing through	(22) Blessing in disguise	(23) Feedback	(24) Intermediary	(25) Self-service
(26) Copying	(27) Cheap short-living objects	(28) Mechanics substitution	(29) Intangibility	(30) Flexible shells and thin films
(31) Porous materials	(32) Color changes	(33) Homogeneity	(34) Discarding and recovering	(35) Parameter changes
(36) Phase transitions	(37) Thermal expansion	(38) Strong oxidants	(39) Inert atmosphere	(40) Composite materials

mode O, S, and D, the explicit value of these n sorts of verbal ratings are $A_1, A_2, \ldots, A_n$, respectively, when the membership value is 1, and the weights assigned to each rating above are $\omega_1, \omega_2, \ldots, \omega_n$ apiece, and finally, the defuzzification value Z_j of the failure mode j calculated through the method of maximum weighted mean turns to be

$$Z_j = \frac{\left(\sum_{i=1}^{n} \omega_i \times A_i\right)}{\sum_{i=1}^{n} \omega_i}. \quad (3)$$

3.5. Theory of Inventive Problem-Solving (TRIZ). To go a step further, Marsh et al. [9] incorporated 40 inventive principles with the educational domain and put forward another 40 inventive principles targeted specially for latter, with each principle supported by corresponding explanations and cases. As their method is more conducive to our further cross-reference, deeper understanding of how these 40 principles are interpreted in the educational domain can be ensured, thus forging the requisite for the elimination of innovation issues residing in the educational domain in the means of TRIZ. There is a sum of 40 inventive principles for education, as shown in Table 2.

Modeling after the classic TRIZ, Mann [8] brought up the technical contradictory parameters aimed at the field of engineering technology, along with 31 parameters applied in the area of business management. When bringing forward the management parameters formulated for education innovation, we have, in connection with the actual situation of education innovation, referred to these business management parameters proposed by Mann [8] as the blueprint and eventually succeeded in redefining the 31 management parameters produced, especially for education innovation in accordance with the sequential process of research and development, production, supply, and support for educational outputs. These 31 management parameters are primarily classified into two parts, with one part used to illustrate the process of providing educational services, namely R&D-production-supply-support, each of which is defined based on the five fundamental characteristics: capability, cost, time, risk, and interface. Table 3 demonstrates with concreteness the entire management parameters. In respect of how to seek the principles of innovation, two approaches are the most striking: one is to draw on the correlation chart between the parameters and the principles of innovation discovered by Mann [8] through a large number of case studies in the field of business management (refer to Mann [8] for details); another is to apply the contradiction matrix in which those principles of innovation frequently used in perfecting every management parameter have been summarized in the correlation chart between the parameters and the principles of innovation.

All the inventive principles are effectively linked with management parameters (refer to Mann [8] for details). A total of 31 management parameters could formulate a 31×31 contradiction matrix, of which each parameter is likely to connect with the rest 30 parameters to regenerate a parameter pair of contradiction. Since the targeted principle of innovation involved in each parameter pair has been expounded in that parameter pair of contradiction, all the specific principles of innovations could at bottom be disclosed in the process of modal analysis if we attempt to connect the parameters and the contradiction matrix involved in the case studies of Section 4 with corresponding inventive principle set.

4. Results

4.1. Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). Table 4 presents the failure mode of the teaching system selected through Delphi method. After each of the five experts had fulfilled the fuzzy FMEA questionnaire, we adopted the rule base of 35 fuzzy inferences, which was previously curtailed by Pillay and Wang [11], and later, we discovered the fuzzy rule base with the corresponding risk to rate their risk priority. Finally, we employed both the experts' weight allocation and formula (3) in defuzzifying each risk priority. When the membership function of verbal rating amounted to 1, the explicit values of all the verbal ratings depicting the risk priority were as follows: L (low) = 0.055, FL (fairly low) = 0.461, M (moderate) = 0.911, FH (fairly high) = 2.041, and H (high) = 7.111, as manifested in Table 5. As an interpretation of Table 5, the higher the defuzzification value, the greater the risk priority, equivalently, the greater the risk. It could be remarked from the table that the failure mode with the highest priority revealed

Table 3: 31 management parameters of educational innovation.

(1) R&D capacity	(6) Production capacity	(11) Supply means	(16) Support capability	(21) User needs	(26) Convenience	(31) Stability
(2) R&D cost	(7) Production cost	(12) Supply coast	(17) Support cost	(22) Information volume	(27) Adaptability/functionality	
(3) R&D time	(8) Production time	(13) Supply time	(18) Support time	(23) Information flow	(28) System complexity	
(4) R&D risk	(9) Production risk	(14) Supply risk	(19) Support risk	(24) Exogenous harmful factors	(29) Control complexity	
(5) R&D interface	(10) Production interface	(15) Supply interface	(20) Support interface	(25) Endogenous harmful factors	(30) Competitive pressure	

Table 4: Failure mode of the integrated teaching system of theory and practice.

No.	Failure mode	Failure effect	Failure cause
1	Unsatisfying teaching outcomes	Students' unintentional learning	(1) Insufficient training equipment (FM1) (2) Inadequate space (FM2) (3) Irrational matching between teachers and students (FM3) (4) Teachers' unsatisfactory professional level (FM4) (5) Loud noise in the workshop and lack of sound insulation between workstations (FM5) (6) Students' low comprehensive literacy (FM6) (7) Students' poor foundation in relevant theoretical knowledge (FM7) (8) Unreasonable duration arrangement for both general knowledge class and training class (FM8)
2	Security incidents	Mortal dangers to students and property loss of the school	(1) Students' uncertainty in operations caused by their intensive curiosity (FM9) (2) School's insufficient error-proofing equipment for training (FM10) (3) Students' poor security awareness (FM11) (4) Illegal operation on the lifting machine (FM12) (5) Jack lever's being rotated casually by students (FM13)
3	Teachers' aversion to the integrated teaching of theory and practice	School's inadequate promotion of the integrated teaching of theory and practice	(1) Few genuine dual-qualified teachers (FM14) (2) Trivial preparation for the integrated teaching of theory and practice (FM15) (3) Indifference from school leaders (FM16) (4) Illogical classroom planning for the integrated teaching of theory and practice (FM17)
4	School education's failure in connecting with enterprise production	Employment difficulties (retraining from enterprises regardless of success in getting employed)	(1) Students' aversion to dirty and exhausting tasks and their failure in preserving (FM18) (2) School's underdeveloped training equipment (FM19) (3) Untimely update on teaching contents for auto repair major (FM20) (4) School's failure in keeping up with the developing pace of correlated industry (FM21)

the fact that students were poor in their safety awareness, with a defuzzification value of 5.353, while the mode with the lowest risk priority indicated that the teaching content of the auto repair major failed to get updated in time, with the defuzzification value reaching 0.055.

Risk priority, the key indicator used for failure analysis of a specific teaching system, is a comprehensive evaluation indicator of the potential risk index and the hazard rating of a certain failure element. Based on the defuzzification value Z_j of risk priority, all the obsolescent items involved in teaching activities were ranked according to their degree of optimizing demand from large to small, and the one with the largest value was counted as the service item, which should be improved in the first priority. Among these 21 obsolescent items involved, "students' poor security awareness," "students' uncertainty in operations caused by their intensive

Table 5: Risk priority ranking based on fuzzy rule base.

Failure mode	O	S	D	Risk priority	Z_j	Risk priority ranking
FM1	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274	11
FM2	*L*	*VL*	*L*	*L*, 0.16*FL*	0.111	18
FM3	*VL*	*L*	*L*	*L*, 0.16*FL*	0.111	18
FM4	*M*	*H*	*M*	0.4*M*, 0.66*FH*	1.614	3
FM5	*L*	*L*	*L*	0.86*L*, 0.78*FL*	0.248	15
FM6	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274	11
FM7	*VL*	*M*	*M*	0.5*L*, 0.92*FL*	0.318	10
FM8	*VL*	*H*	*M*	0.86*L*, 0.14*FL*	0.112	16
FM9	*H*	*H*	*M*	0.88*FH*, 0.62*H*	4.136	2
FM10	*H*	*L*	*M*	0.66*M*, 0.94*FH*	1.575	4
FM11	*H*	*H*	*H*	0.52*FH*, 0.98*H*	5.353	1
FM12	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274	11
FM13	*M*	*L*	*L*	0.4*FL*, 0.58*M*	0.727	8
FM14	*H*	*L*	*M*	0.66*M*, 0.94*FH*	1.575	4
FM15	*VL*	*H*	*M*	0.86*L*, 0.14*FL*	0.112	16
FM16	*L*	*M*	*L*	0.4*FL*, 0.58*M*	0.727	8
FM17	*L*	*VL*	*L*	*L*, 0.16*FL*	0.111	18
FM18	*H*	*L*	*M*	0.66*M*, 0.94*FH*	1.575	4
FM19	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274	11
FM20	*VL*	*L*	*VL*	*L*	0.055	21
FM21	*L*	*H*	*M*	0.66*M*, 0.94*FH*	1.575	4

curiosity," and "teachers' unsatisfactory professional level" ascended the top three in the risk assessment ranking, followed in sequence by "school's insufficient error-proofing equipment for training," "few genuine dual-qualified teachers," "students' aversion to dirty and exhausting tasks and their failure in preserving," and "school's failure in keeping up with the developing pace of correlated industry." In subsequent part of this study, these seven items would be probed into as well, along with recommendations for optimization by virtue of TRIZ.

4.2. Optimization of Obsolescent Items Involved in Teaching Activities via TRIZ. FMEA, a sort of method that makes it accessible to plainly point out those obsolescent items needed to be optimized in teaching activities, turns eclipsed in terms of offering effective solutions to problems; thus, other tools are still indispensable. TRIZ, a theory that is both abundant in innovative ideas and powerful in problem-solving, is able to can make up for the deficiencies of FMEA. By applying the TRIZ contradiction matrix, all the technical parameters of these obsolescent items involved in teaching activities would be recapitulated first, and next each obsolescent item would be matched with a corresponding TRIZ parameter wholly in consonance with the matching relation to construct a contradiction matrix. Afterwards, those appropriate inventive principles and methods would be screened out according to the contradiction revealed between the deteriorated and optimized parameters in that matrix.

The essence of TRIZ lies in its astonishing efficiency of faultlessly disposing the failures existing in teaching activities while imposing no harm on these teaching activities. In light of this advantage, either the innovation principles were unearthed in this research according to TRIZ parameters corresponding to related teaching failures exhibited in Mann [8], or the failure parameters involved in teaching activities were brought into the contradiction matrix for further analysis under the guidance of corresponding principles. Whichever approach had been adopted, the ultimate goal was to promote the teaching quality by formulating targeted optimization measures, which could be applied in successfully eliminating the failures remaining in teaching activities and subsequently lowering the failure risk of teaching activities. Despite several repeated TRIZ inventive principles in the contradiction matrix, each optimization measure varies depending on the failure mode. In the analysis of the FMEA model, a couple of optimization measures were released in conformity with the seven obsolescent teaching items in this study based on the TRIZ principles. Concerning the rest teaching failures, the principles employed in purging them maintained the same, with the defuzzification value interpreted according to the risk priority number as follows.

4.2.1. Failure Modes 11, 9, and 18: "Students' Poor Security Awareness," "Students' Uncertainty in Operations Caused by Their Intensive Curiosity," and "Students' Aversion to Dirty and Exhausting Tasks and Their Failure in Preserving". Currently, schools are unsurprisingly confronting a series of thorny problems about talent cultivation pervading at the primary education stage, such as students' lack of not just professional interest, but practical ability and innovative spirit, and primary education's disengagement with higher education. These phenomena of "students' poor security awareness," "students' uncertainty in operations caused by their intensive curiosity," and "students' aversion to dirty and exhausting tasks and their failure in preserving" selected from the failure modes are none other than the most vivid reflections towards those problems. As "reliability" existing among the parameters is interpreted into "reactions that a system, an organization or an individual has produced towards changes from the outside," it is rational to claim that this model embodies the parameter of "reliability." Accordingly, we are permitted to extract these inventive principles of 15, 17, 23, and 40 related to the parameter of improving reliability according to Mann [8], with details explained as follows.

First and foremost, the measurement of "pedagogy discussion among teachers coming from different or similar disciplines" embodies the 15th inventive principle "dynamics" and the 40th principle "composite materials." With regard to dynamics, its third dimension refers to "to make movable or reliable a system or process which is originally rigid or inflexible." Through this measurement, the originally rigid form of a team within which only the teachers belonging to the same discipline are allowed to exchange and discuss has successfully been upgraded into a cross-communicating form suitable for multiple disciplines, thus rewarding teachers with the chance of both acquiring multidisciplinary knowledge and fostering their own ability of adapting their educational contents in line with the social needs. When it comes to the principle of composite materials, it is deemed as a process where a system or organization shifts from the original single structure to a composite (diversified) structure, or a conjunction of which multiple skills or abilities are consciously applied. The practice of "pedagogy discussion among teachers coming from different or similar disciplines" facilitates the teacher team system's transitioning from an isolated mode where teachers responsible for a specific discipline focus merely on that subject to a multi-composite structure where cross-explorations are accessible among diverse disciplines. By such practice, teachers stay conscious in giving full play to their personal competencies in that discipline and are allowed to effectively link their own subject with the contents of the rest ones, thus continuously promoting the comprehensive ability of the entire teacher team. This has ideally reflected the composite materials of the 40th inventive principle.

In the second place, the measurement of "pedagogy discussion among teachers coming from different or similar disciplines" above reflects in like manner the fourth meaning of the 17th inventive principle "another dimension," which means "to place an event on one side by tilting or relocating it." By the practice of "pedagogy discussion among teachers coming from different or similar disciplines," the vertical teacher team of a single discipline needs to be tilted and transformed into a horizontal exchanging team composed of diverse disciplines, thus symbolizing the 17th inventive principle.

Thirdly, the practice of "reflection" from students reveals the first meaning of the 23rd inventive principle, namely "to optimize a process or an action by bringing in feedback (backtracking or cross-checking)." Students' "reflection" is performed in a self-criticism form for the perfection of their own thinking and behaving, undoubtedly embodying the inventive principle "feedback."

4.2.2. Failure Mode 4: Teachers' Unsatisfactory Professional Level. In allusion to the self-enclosed pattern currently prevailing in schools, together with their worrying notion that teachers are attached to them, reforms are in dire need not only in which direction schools are marching forward but in how to train teachers. By bridging between this failure mode and the set of contradictory parameters, namely system complexity and stability, we discovered that the worsen the parameter of system complexity ran, in other words, the more complex the development direction and the method of training teachers in schools trended, and the better the stability would evolve, which was reflected by the overall stable development of schools within a county. Otherwise, the stability would deteriorate (remain unchanged or decline). This discovery is absolutely a persuasive demonstration of the contradiction between the two parameters: system complexity and stability. Accordingly, we are eligible to pick out these inventive principles of 15, 17, and 26 involved according to the contradiction matrix (Mann [8]), with details depicted as follows.

First of all, the resolution of "dismantling schools' self-enclosed pattern and promoting interactions among each other based on schools' partnership developing" manifests the third dimension of the 15th inventive principle "dynamics," which is "to make movable or reliable a system or process which is originally rigid or inflexible." This dimension works ideally in concert with the cooperative education program among higher vocational colleges as the latter attempts to transform the original inflexible "self-enclosed pattern" into a mobile and adaptable school-running one, which is marked by "mutual interaction with other schools."

Next, both the 17th inventive principle "another dimension" and the 26th one "copying" are precipitated in the endeavor of "eradicating the conventional pattern that teachers remain still where they are working for and meanwhile arranging remote exchanges or regional dispatches with the core goal of facilitating communications amongst teachers from different schools." The measure of teachers' "remote exchanges or regional dispatches" is counted as a type of transformation for training teachers from the initial unitary mode that "teachers remain still where they are working for" into a two-dimensional or three-dimensional training model, which involves "remote exchanges or regional dispatches," thereby precipitating the inventive principle "another dimension." Regarding the principle "copying" whose first dimension lies in "referring to successful experience from another system or another part of certain system," it is favorably reflected in the initiative where teachers interact with each other or are dispatched to other regional schools as they are by the same token learning or referring to the successful experience from other teachers or teams.

4.2.3. Failure Mode 10: School's Insufficient Error-Proofing Equipment for Training. The auto technology specialty of each school, in the face of neither a single enterprise nor enterprises of the same category, is required to take into account the job assignments from various enterprises instead when setting up training devices or error-proofing equipment. All these assignments ought to be analyzed, aggregated, and summarized attentively so that contents that share general similarities could be sorted out for further teaching. At the mention of teaching contents, they are anticipated to be utilized in facilitating students' extensive acquisition of both professional knowledge and skills, ranging from getting familiar with the equipment, selecting the equipment, wiring, programming, to debugging and operating, in order for the design and completion of a project. In the process of setting up training devices or error-proofing equipment, project-based teaching is bound to receive effective acceleration in its implementation, execution, and promotion.

The essence of all the conflicts above resides in whether the quality and quantity of courses offered in schools are able to meet the requirements raised by each party. With added equipment, devices, or time provided, every conflict would be swept away thoroughly. Nevertheless, the school system is well-defined without any significant modifications. In this sense, further generalization could be executed based on TRIZ since it is workable to transform both the quality and quantity of training devices or error-proofing equipment into the parameter "volume of information (data)," and the school system into the parameter "waste of time." In such manner, the conflict above could be converted into a contradiction between the parameter "volume of information (data)" and the parameter "waste of time." Hereby, we are qualified to pick out these inventive principles of 2, 13, and 17 involved according to the contradiction matrix (Mann [8]), with details manifested as follows:

Inventive Principle 2: Taking Out (Extraction). This inventive principle means either to extract the negative parts or attributes from an object, or to extract only the essential parts or attributes from it. In accordance with this principle, two measurements are exceptionally recommended. For one thing, students need to be divided and distributed into separate majors with differing cultivating orientations after they have got enrolled at school, to guarantee the seamless connection with diverse selective demands from enterprises. For the other, job assignments from enterprises ought to be summed up before both the typical assignments and the error-proofing knowledge are extracted. By converting these typical assignments and the error-proofing knowledge into students' learning tasks, which will further be split up for teaching in different areas, the teaching content of specialized courses is empowered to better reflect the basic skills, error-proofing knowledge, and professional quality mandatory for corporate production.

Inventive Principle 13: The Other Way Round. The central meanings of this principle are as follows: the first is to invert the action(s) used to solve the problem; the second is to make movable parts or the external environment fixed and fixed parts movable; the third is to turn the object or process "upside-down" or "inside-out." Based on this principle, a couple of countermeasures for optimization are offered, involving to switch the teaching method and create realistic situations, to teach with the task-oriented method, to strengthen students' ability in logical thinking and problem-solving, and to block occupational security incidents caused by mistakes.

Inventive Principle 17: Another Dimension. This principle is illuminated in these ways: to move an object in two- or three-dimensional space; to use a multi-story arrangement of objects instead of a single-story arrangement; to tilt or reorient the object, laying it on one of its sides; and to use "another side" of a given area. The strategy derived from this principle is to impart to students knowledge in regard to safety protection and innovation and entrepreneurship in addition to those vocational courses, so that satisfactory achievements could be reaped not only in expanding students' employment space but also in boosting students' sustainable development.

4.2.4. Failure Mode 14: Few Genuine Dual-Qualified Teachers. Being exposed to the prevailing lack of "high-quality skilled talents" caused by the social separation among production, education, and research, corresponding countermeasures are in dire need to accelerate the development of skilled personnel by fortifying cooperation between universities and enterprises. In the analysis, we attempted to link this failure mode with the two contradictory parameters of supply means and adaptability, and thereby discovered that when the parameter of supply means deteriorates, in other words, the talent training mode grows complicated, and the parameter of adaptability will consequently ameliorate, which is reflected in the capability of being able to react to various existing challenges; otherwise, the parameter of adaptability will deteriorate (stay unchanged or fall). This relationship successfully reveals the contradiction between the two parameters of supply means and adaptability. In this sense, we are entitled to pick out these inventive principles of 7, 13, 15, 17, and 19 involved according to the contradiction matrix (Mann [8]), with details given as follows.

As for the first initiative above all, schools are suggested to interconnect intensely with enterprises, industries, and industrial parks for the ultimate accomplishment of point-line-surface cooperation, embodying the 5th innovative principle "merging" and the 15th principle "dynamics." The first implication of "merging," that is, "to bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations," is properly illuminated by the aggregation of schools' teaching functions when enterprises, industries, and industrial parks interconnect spatially with campuses. In terms of the principle "dynamics," whose third meaning is "to make an object (or process) movable or adaptive if it is rigid or inflexible," it can be rationally mirrored since the precise reason why schools collaborate with enterprises is that they desire to cultivate skilled talents who are adaptable enough by reforming the original teaching pattern that used to be rigid and inflexible in a written form.

Next, the move of "perfecting the education and training service system and carrying out social training" visualizes the first meaning of the 17th inventive principle "another dimension": "to move an object in two- or three-dimensional space." To be more specific, the original school training was carried out merely at campus, while the reformed training mode is largely extended to multiple dimensions, which involve both enterprises and even the entire society.

Last but not least, schools are greatly advised to "participate in constructing a technological innovation system in which not only enterprises act as the main body and the market is looked up as the orientation, but production, education, and research are jointly connected, and meanwhile launch scientific research services of various disciplines." Such movement manifests the first denotation of the 7th inventive principle "nested doll": "to place one object inside another; place each object, in turn, inside the other." To put it more vividly, the objective of this movement is precisely to place sequentially enterprises and the market inside the construction of that technological innovation system where production, education, and research are jointly connected.

4.2.5. Failure Mode 21: School's Failure in Keeping Up with the Developing Pace of Correlated Industry. Same as the analyzing method in Section 4.2.3, we are definitely qualified to single out these inventive principles of 2, 3, 7, 13, 17, 19, and 28 involved according to the contradiction matrix (Mann [8]), with specific explanations offered as follows.

The inventive principles of 28, 2, and 7 are rather applicable with regard to the cultivation goals of technical professionals in vehicle. Hereby, schools are supposed through specific investigations to probe into optimal talent cultivating programs and related curriculum with enterprises' joint efforts, so that students could be trained in differentiated directions. Besides, brotherly collaboration between schools and enterprises is vital in setting up labeled or predetermined class in response to several companies' individual demands. In reference to the inventive principles of 13 and 28, schools are suggested to strengthen their construction of practical training in which teachers will be allowed to instruct students as if they were exposed to the real-life situation. Additionally, practical training classrooms jointly launched by both schools and enterprises are indispensable for the publicity of corporate culture, thus permitting students an advanced understanding of a company. Under the 7th inventive principle, the collaboration between the two parties needs to be consolidated by dispatching teachers to a specific company as interns to enhance their practical ability. Likewise, technical backbones from enterprises are highly recommended to be invited for campus lecturing. Through all these measures mentioned above, students are rendered great chances of not only getting familiar with the developing trend of both industries and enterprises when still at campus, but mastering essential knowledge and skills needed, so that they are highly likely to familiarize themselves with the future position the moment they begin their career.

From the perspective of teaching mode, specialized courses need to be designed in accordance with the integrated form of theory and practice when the inventive principles of 2 and 7 are referred to. In this manner, an ideal integration of teaching, learning, and practicing would be achieved through the pathway of "learning by teaching and practicing by learning." Teachers are expected to conduct their classes with the task-oriented or project-directed approach as frequently as possible. Through the application of typical job assignments and the creation of authentic situations, not only will the teaching contents prove more functional, but also students are prone to appreciate what they have acquired, finally contributing to enterprises' recognition of those students' professional competence.

In respect of the course content, it is desperately recommended based on the 2nd and 3rd inventive principles that the courses of both auto mechanics and auto maintenance service should be added to the professional basic curriculum. As for the professional core curriculum, supplementary courses in need would contain introduction to new-energy vehicles, principles and technology of auto electronic control, chassis technology and maintenance of new-energy vehicles, driving motor and control technology, power electronic technology of new-energy vehicles, management and maintenance technology of traction battery, comprehensive performance inspection of new-energy vehicles, and fault diagnosis of new-energy vehicles. Concerning the professional extension one, additional courses such as auto insurance and claims, appraisal and evaluation of used cars, and customer relationship management ought to be taken into consideration.

As seen from the arranging sequence of courses, the course of introduction to new-energy vehicles is supposed based on the 3rd inventive principle to be given priority, followed in order by the course of principles and technology of auto electronic control, chassis technology, and maintenance of new-energy vehicles, as well as driving motor and control technology. Afterwards, the course of power electronic technology of new-energy vehicles, along with the course of management and maintenance technology of traction battery, ought to be scheduled prior to comprehensive performance inspection of new-energy vehicles and fault diagnosis of new-energy vehicles. After having completed all the courses above, students are required in line with the talent cultivating program to be dispatched into separate enterprises for internship so that they would get familiar with the company's manufacturing process and post-settings.

In the matter of students' sustainable development, schools are advised based on the 19th inventive principle to continue adding the course of secondary vocational students' cultural accomplishment, as well as the course of speech and eloquence prior to the following ones: practical writing, etiquette for public relations, auto insurance and claims, appraisal and evaluation of used cars, and customer relationship management. By the means of offering extended courses, not only will students' horizons be widely enriched, but their professional qualities tend to be lifted as well.

On the subject of innovation and entrepreneurship, setting up the course of career planning is inevitable of enormous value, so are the course of entrepreneurship education and the course of employment guidance. By offering the course of career planning, students are far more likely to figure out what kind of goals they are supposed to set rationally for the future and what aspects they need to accumulate precisely. For the arrangement of the latter two courses, however, the primary objective is to respond positively to China's call for the entrepreneurship and innovation among the general public and to help equip students with a solid foundation for both learning and entrepreneurship.

4.3. Validity Verification of Teaching Activities Optimized via TRIZ. After the semi-annual implementation of 6 teaching activities proposed according to these optimizing strategies of FM4, FM9, FM10, FM11, FM14, FM18, and FM21 based on TRIZ in the targeted school chosen as our case study, we continued to conduct another survey among the 5 experts previously mentioned, employing the fuzzy FMEA questionnaire on 21 ineffective teaching activities, with the final result illustrated in Table 6. By the paired-samples t-test (shown in Table 7), we noticed that the average value Z_j

Table 6: Ranking of risk priority based on the fuzzy rule base (posttest).

Failure mode	O	S	D	Risk priority number	Z_j
FM1	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274
FM2	*L*	*VL*	*L*	*L*, 0.16*FL*	0.111
FM3	*VL*	*L*	*L*	*L*, 0.16*FL*	0.111
FM4	*L*	*M*	*L*	0.4*FL*, 0.58*M*	0.727
FM5	*L*	*L*	*L*	0.86*L*, 0.78*FL*	0.248
FM6	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274
FM7	*VL*	*M*	*M*	0.5*L*, 0.92*FL*	0.318
FM8	*VL*	*H*	*M*	0.86*L*, 0.14*FL*	0.112
FM9	*M*	*M*	*M*	0.92*M*, 0.84*FH*	1.450
FM10	*M*	*L*	*M*	0.94*FL*, 0.46*M*	0.336
FM11	*M*	*L*	*L*	0.4*FL*, 0.58*M*	0.727
FM12	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274
FM13	*M*	*L*	*L*	0.4*FL*, 0.58*M*	0.727
FM14	*L*	*L*	*L*	0.86*L*, 0.78*FL*	0.248
FM15	*VL*	*H*	*M*	0.86*L*, 0.14*FL*	0.112
FM16	*L*	*M*	*L*	0.4*FL*, 0.58*M*	0.727
FM17	*L*	*VL*	*L*	*L*, 0.16*FL*	0.111
FM18	*L*	*L*	*M*	0.4*FL*, 0.58*M*	0.562
FM19	*VL*	*H*	*L*	0.58*L*, 0.68*FL*	0.274
FM20	*VL*	*L*	*VL*	*L*	0.055
FM21	*L*	*M*	*L*	0.4*FL*, 0.58*M*	0.727

Table 7: Paired-samples *t*-tests for the difference in mean perceptions between formal test and posttest in Z_j ($N = 21$).

	Paired differences					df	*t*	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower	Upper			
Posttest—formal test	0.60124	1.15869	0.25285	0.07381	1.12867	20	2.378	0.027

dropped significantly, which undoubtedly proved the distinct optimizing effect of TRIZ on the school's teaching activities within half a year.

5. Discussion

By selecting the auto repair specialty of some secondary vocational school in Suzhou City of China as the research objective, the researcher has collected and subsequently analyzed all the failure factors existing in each teaching activity by dint of failure mode and effect analysis (FMEA). Based on the exploration of each index's failure risk, optimizing plans have been formulated according to the ranking of each failure factor's risk priority number, during which TRIZ was referred to. In the light of several experts' suggestions and TRIZ inventive principles, a contradiction matrix was formed before eventually laying down for schools' reference these efficient improvement measures targeted at the top seven service failure projects. During the previous course teaching of auto chassis maintenance, teachers got used to imparting pure theoretical knowledge, most of which proved relatively boring and outmoded. Nevertheless, regarding the course of auto electronics technology itself, whose ultimate goal is to cultivate comprehensive-quality talents with both high practical ability and proficient skills, the purely theoretical teaching contents currently adopted have obviously deviated from the original teaching objective intended. Hereby, the unceasing application of modern teaching contents contained in TRIZ is definitely of vital significance to schools by vigorously citing as many real-life cases as possible at class to enhance the previous teaching contents that used to be highly out of times. Considering the high-degree operability of the auto chassis maintenance course, it would be far from enough to effectively promise students' complete grasp of relevant course principles and theories merely by the book-based teaching of theories alone. In this aspect, extra practical operating courses are rather compulsory when schools are dealing with the course setting. Only by putting what has been learned theoretically at class into practical operating are students more likely to gain a deeper understanding and a more flexible grasp of the knowledge obtained in class. Hence, constant innovations based on TRIZ can never be neglected when teachers attempt to ingeniously combine what students are interested in with the theories imparted in class. In practice training, students could be divided into study groups in which they will be granted the great opportunity of sublimating their study by applying what they have mastered from books to practical operating. Moreover, enhanced interactions with students are of similar prominence in the classroom where teachers ought to allow their students to think proactively and independently to put forward wise and innovative solutions. It has been verified in this study that both FMEA and inventive principles of TRIZ are proved to be ideal functional tools for the curriculum construction of auto technology specialty. By means of resource integrating and curriculum optimizing, not only are enterprises' demand for human resource and schools' teaching conditions taken into consideration, but incessant enhancement in teachers' qualification and sustainable cultivation of students are also spotlighted. At the same time, organic bond between schools and enterprises could be attained through these optimizing measures without a hitch, and all parties' enthusiasm would be effectively mobilized to participate in this mission, thus achieving the ultimate coordinated development and all win of each party.

6. Conclusion

Despite these relatively appreciable conclusions attained in this research, a couple of limitations still exist, waiting for further perfection. For one thing, an overall probe has not yet been accomplished into these teaching activities, part of which were not explored due to their imperceptible failure modes. In addition, merely five individuals were given the expert questionnaires, all of which have been assembled and then evaluated. Given the opportunity of distributing the expert questionnaires among more targets, the outcome of this study would be slightly different. In the meantime, selecting several business executives or those veteran auto repair staff as the first batch of test objects is comparatively worthy of taking a crack at since the abundant practical experience from people of this category will definitely conduce to a more accurate feedback on these questionnaires. For the other, both the application and probe of FMEA into the educational industry are still in their infancy regardless of several decades' development of FMEA, consequently leading to the deficiency in relevant literature and publications that could be used for reference. Concerning the conclusions obtained in this research, subsequent perfections are still needed through further associative research. In light of the fact that the numerical ranking of RPN calculated within FMEA here was directly identified as the priority of improvement, follow-up scholars are suggested to use the complete quantitative values with reference to the RPN formula mode proposed in this research so that their research outputs would be more befitting and applicable in the education field. Likewise, attempts to use methods such as multi-criteria decision-making (MCDM) are also worth trying when assessing the failure mode. Last but not least, it is of the great potential that a fresher type of interpretation of the research outcomes will be garnered if that research is undertaken in other research areas.

Data Availability

The data will be made available upon request to the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Article

Human Resource Scheduling in Project Management Using the Simulated Annealing Algorithm with the Human Factors Engineering Approach

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Manpower scheduling means assigning a work pattern (shift day) according to the wants and needs of the system and the workforce with the goal of minimum cost. Many production and service systems require multiple scheduling. This problem is generally NP-complete, and it takes a long time to solve it through the current method. Today, several innovative methods have been proposed to solve such problems. In this paper, the simulated annealing method (SA) has been used. The problem in this study is in an oil extraction project for human resource scheduling, which consists of three human resource groups in four task types in oil exploration operations, including geology, geophysics, petrophysics, and oil engineering. To solve the human resource scheduling problem, a meta-heuristic algorithm called simulated annealing algorithm was applied, and the result indicated that the allocated human resource was scheduled with the least fatigue implementing the proper job rotation.

1. Introduction

Preparing a favorable timetable for work shifts and workflow of employees with the approach of human factors engineering requires careful attention to the characteristics of employees such as satisfaction, health, stress, motivation, and so on. To increase employee satisfaction and health, using job rotation schedule and multiskill staff is a very appropriate method. But the costs of relocation increase the costs of the organization [1].

Naft-e-Khazar Company was established in January 1998 as one of the subsidiaries of the National Iranian Oil Company. The company is responsible for the exploration, development, and production of hydrocarbon resources in the South Caspian Basin and the three coastal provinces of Mazandaran, Golestan, and Gilan. Monitoring the implementation of all contracts concluded between the National Iranian Oil Company and international companies for the study and development of oil fields in the Caspian Sea, as well as monitoring environmental issues associated with the exploration and development of oil and gas reserves in the Caspian Sea are the responsibilities of the Naft-e-Khazar Company. The geology consists of three sections: geological studies, operations, and laboratories. The studies section is the basis of any exploration operation, and its study technical output is provided to other departments of the geological survey. Geophysics includes departments for monitoring the operation of geophysical data, monitoring the processing of geophysical data, geophysical data interpretation, and management system department. Seismic surveys, data processing, and interpretation, as well as the study and design of seismic lines, are among the geophysics department's activities. The aim of petrophysics is to identify underground hydrocarbon reservoirs and evaluate the rock and fluid properties of the reservoir, and its output is the static and dynamic description of the reservoir and how the fluid is distributed in the well and beyond. However, the job rotation advantage in enhancing performance has not been confirmed with certainty. The use of very simple and nonheuristic rules, such as allocating different tasks relative to what has been done by the operator in the past period, does not lead to performance enhancement, and it is necessary to develop models based on heuristic rules in a way that performance enhancement is achieved by modifying how tasks are scheduled [2, 3].

The main objective of the paper is to develop a plan for the problem of job rotation scheduling to overcome workers' double fatigue. For this purpose, the main question of the paper is how to develop a plan for the problem of job rotation scheduling to overcome the double fatigue of workers. Therefore, the main contribution of the paper is as follows:

(i) A nonlinear integer model is proposed for the job rotation scheduling problem
(ii) A new idea is suggested for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator
(iii) The proposed model can calculate allocation costs; the fatigue cost could be included in job rotation scheduling; and decision efficiency could be developed
(iv) Simulated annealing meta-heuristic search algorithms will also be implemented to solve the model

The rest of paper is organized as follows: Section 2 presents a literature review. Section 3 presents research methodology. Section 4 presents results and unique research finding. Section 5 presents managerial insights and practical implications, and finally, Section 6 presents conclusion and suggestions for further research.

2. Literature Review

The model of the workforce scheduling program in service and production systems is considered by creating a work pattern for each staff [4]. Application and job rotation encompass a wide range of manufacturing companies; a variety of tasks; advanced industrial systems, such as cellular manufacturing industries; and service organizations, such as hospitals, police departments, fire departments, bus companies, and so on [5]. However, research on the impacts of employing job rotation has yielded contradictory results in practice in which its advantage in improving employee performance cannot be considered conclusively proven [3]. In this regard, Bhadury and Rdovilsky [6] have presented three multiperiod and two-objective allocation models and some simple heuristic methods to obtain the desired justified answers and claim that these three models are more effective than previous models and are closer to reality. Huang et al. [7] categorized the constraints to solve the problem with a large number of nurses, longer planning time, and many constraints using an evolutionary algorithm. According to him, the more nurses and the time we plan for it, the more complex the problem becomes. Avadí et al. [8] modeled the problem definitively and solved it using a hybrid algorithm. This solution method combines two evolutionary meta-heuristic algorithms and local search to improve the generated solutions. Santos et al., using the concept of integer programming, solved the problem in an innovative way. In this study, the absence of nurses has been proposed as an effective factor in the schedule. Hochdörffer et al. [4] in their study planned a short-term employee scheduling system. Demographic change is a well-known influencing factor challenging social security systems in industrialized countries. In a manufacturing context, companies need to cope with an increasingly heterogeneous workforce in terms of qualification and impairments, as well as increasing average age. The improvement of more standardized processes and the trend to move towards shorter lead times, paired with demographic changes in the workforce reveal strong importance of staff planning. A short-term staff planning system, which generates job rotation schedules taking into consideration workers' qualifications, the workplace's ergonomic exposure, and the most recent allocations of each worker, is sought to ensure the right worker is allocated to the right workplace at the right time. The arising complexity of such scheduling problems is met in this study by implementing a linear programming-based heuristic, which solves the scheduling problem gradually for each rotation around and generates a holistic job rotation schedule for an entire workday. The presented approach to short-term staff scheduling is used in a VBA-based software prototype and was tested in the final assembly line of a German automotive manufacturer. Ayough et al. [9] in their study investigated the performance of human resources with respect to forgetting, boredom, and learning. The performance of a manufacturing cell depends on an efficient layout design and optimal work schedules. However, the operator-dependent factors such as learning, forgetting, motivation, and boredom can considerably impact the system output. In this study, we consider heterogeneous operators with dynamic performance metrics and integrate the job assignment and job rotation scheduling problems with the balancing and production sequencing in a U-shaped lean manufacturing cell. A novel multiperiod nonlinear mixed-integer model is presented to minimize the deviations from tact time and the number of operators in a finite planning horizon. An efficient meta-heuristic approach is developed to solve the problem, and the results are compared to a static case where no human factor is included. The computational results demonstrate that including the operator-dependent metrics could develop the cell design performance. Lotfi et al. [10] recommended using blockchain technology (BCT) for growing faster in each country. They believe it is essential to apply BCT in supply chain network design (SCND) and is considered by the designer and manager of a supply chain. For this, Lotfi et al. [11] presented a survey applicable blockchain technology (BCT) in project management for the first time. For this purpose, a resource-constrained time-cost-quality-energy-environment tradeoff problem is presented by considering BCT, risk, and robustness (RCTCQEETPBCTRR) in project scheduling. The proposed framework utilizes hybrid robust stochastic programming, worst case, and conditional value at risk (CVaR) to cope with uncertainty and risks.

2.1. Research Gap. Previous studies have focused on analyzing and prioritizing key human resources in organizations. Therefore, it is necessary to propose a new idea to calculate the cost of fatigue of each operator by introducing positive and negative fatigue due to the similarity of the tasks assigned to each operator. For this purpose, a nonlinear integer model for the work rotation scheduling problem is proposed in this research; the proposed model can calculate the allocation costs; the fatigue cost can be included in the job rotation planning; and the decision efficiency can be developed. Finally, the implementation of simulated meta-heuristic search algorithms will also be implemented to solve the model.

3. Research Methodology

Scientific research is divided into three categories based on the purpose of research: applied, and research and development. In this classification, the present study is in the group of applied research. The purpose of applied research is to develop applied knowledge in a specific field. In other words, applied research leads to the practical application of knowledge. In fact, applied research is research that uses the cognitive context and information provided by basic research to meet human needs. To formulate the theoretical framework of the research, previous researches have been studied and evaluated and the theories, concepts, and variables are developed based on them. The solution method used in this research is a meta-heuristic algorithm.

3.1. Model Assumptions. The main assumptions of the paper are as follows:

(i) There is no time limit for doing the set of tasks in each planning period
(ii) There is no time limit for the availability of each operator in each planning period
(iii) The allocation of similar tasks is evaluated as favorable in each planning period and as unfavorable in several planning periods
(iv) All parameters and problem data are definite and constant in each planning period

3.2. Definitions and Symbols of the Model. If the number of planning periods (without losing the generality of each period from now on is considered a working day) is equal to K, the counting indices of the parameters and variables of the problem decision and the parameters are symbolized as follows.

3.2.1. Indices

i: operator $(i = 1, 2, \ldots, I)$
j: task $(j = 1, 2, \ldots, J)$
K: day $(K = 1, 2, \ldots, k)$

3.2.2. Parameters

C_{ij}^{k}: cost of doing task j by operator i on day k.

$p_{j'j}$: the amount or degree of similarity of the two tasks j and j'.

DOR: the number of days during which the degree of similarity of the tasks allocated to each operator is calculated. That is, if the goal is to calculate the degree of similarity of the tasks allocated to operator i to day k, days $K - \text{DOR} + 1$ to K need to be considered. Obviously, the DOR is smaller than K.

a_1: cost of daily fatigue of operator i felt as a result of the allocation of tasks throughout the planning period.

3.2.3. Decision Variables

x_{ij}^{k}: if task j is allocated to operator i on day k, it will be equal to one. Otherwise, it will be equal to zero.

z_1: if the total operator fatigue value is negative, it is zero. Otherwise, it is one.

The following are definitions that lead to the calculation of the cost of fatigue due to the allocation of similar tasks during planning periods to each operator.

3.2.4. Positive Fatigue. For each operator on each day, $B(i, k)$ is created due to the similarity of the tasks allocated to the operator on that day. If the operator is allocated only one job on a particular day, the favorable fatigue for the operator is equal to 1.

$$\forall k = 1, 2, \ldots, k; \forall i = 1, 2, \ldots I, \tag{1}$$

$$B^{+}(i, k) = \sum_{j=1}^{j-1} \sum_{u=1}^{J-j} x_{\text{ij}}^{k} \cdot x_{\text{ij}+u}^{k} + P_{\text{jj}+u}. \tag{2}$$

3.2.5. Negative (Unfavorable) Fatigue. For each operator on each day, $B^{-}(i, k)$ is calculated based on the similarity of the assigned tasks from the kth day to the DOR-1 day before.

$$\forall k = 1, 2, \ldots, k; \quad \forall i = 1, 2, \ldots I,$$

$$B^{+}(i, k) = \sum_{t=1}^{\text{Min}\{k-1,\text{DAYS-OFF-ROTIN}-1\}} \sum_{j=1}^{j-1} \sum_{u=0}^{J-j} x_{\text{ij}}^{k} \cdot x_{\text{ij}+u}^{k} + P_{\text{jj}+u}. \tag{3}$$

3.2.6. Total Fatigue of Operator (i) BORNING. It is the fatigue that the operator feels during the planning period and is equal to the difference in the share of each day of maximum fatigue due to the similarity of the allocated tasks on DOR consecutive days and the minimum favorable fatigue for allocating similar tasks.

$$\forall k = 1, 2, \ldots, k; \forall i = 1, 2, \ldots I,$$

$$\text{BORNING}(i) = \frac{\text{Max}_k\{B^-(i,k)\}}{\text{DOR}}\text{MIN}_k\{B^+(i,k)\} \longrightarrow \text{BORNING}(i) = \frac{B^-(i)}{\text{DOR}}B^+(i). \tag{4}$$

There will be no cost if the total operator fatigue value is negative.

3.3. The Proposed Model. The objective function in this model (equation (5)) consists of two expressions: the first is the total cost of the task performed by each allocation and the second is the sum of the fatigue cost of each operator due to the feeling of fatigue because of the allocation of similar tasks over the planning horizon, which is formulated nonlinearly.

$$\text{Min}\, Z = \sum_{t=1}^{i}\sum_{j=1}^{j}\sum_{k=1}^{k} c_{\text{ij}}^{k} \cdot x_{\text{ij}+u}^{k} + z_i \sum_{i}^{i} \text{BORINIG}(i), \tag{5}$$

$$\sum_{i=1}^{I} x_{\text{ij}}^{k} = 1 \quad \forall k = 1, 2, \ldots, k; \forall i = 1, 2, \ldots I, \tag{6}$$

$$\sum_{j=1}^{J} x_{\text{ij}}^{k} = 1 \quad \forall k = 1, 2, \ldots, k; \forall i = 1, 2, \ldots I, \tag{7}$$

$$x_{\text{ij}}^{k} = 0, 1, \tag{8}$$

$$z_i = 0, 1, \tag{9}$$

$$(I - z_i)M + \text{BORNING}(i) \geq 0 \quad \forall i = 1, 2, \ldots, k, \tag{10}$$

$$-z, M + \text{BORNING}(i) \leq 0 \quad \forall i = 1, 2, \ldots, k. \tag{11}$$

Equation (7) based on assumption (2) and inequality (8) and of equations (9) and (10) expresses the model being an integer (of type zero and one). Inequalities (10) and (11) make the constraint of the operator fatigue being positive operational to calculate the associated cost.

3.4. Algorithm Design. Simulated annealing is a random search technique for global optimization problems in which the process of producing solid crystals from molten material is modeled by cooling the melt. The slower the rate of temperature decrease in the molten material, the slower and more orderly the solid crystals are formed. As a result, the resulting solid will have less porosity, and the solid crystal will be in a better position in terms of impact resistance. Therefore, the annealing process involves precise control of temperature and cooling rate. It can also be stated that the performance of the simulated annealing algorithm equals dropping a few rolling balls on an uneven surface. As the balls bounce back and forth and lose energy, they eventually focus on some local minima. If the balls are allowed to jump around enough, that is, to lose enough energy and slowly, some of the balls will eventually fall into the lowest global place (global minimum). Therefore, the global minimum will be obtained. The simulated annealing algorithm is as follows:

(1) Define the objective function and adjust the algorithm parameters

Define initial temperature T and initial value $x^{(0)}$

Define final temperature T and number of iterations N

Define the temperature decrease rate α

(2) Until $(\mathbf{n} < \mathbf{N}, \mathbf{T} > \mathbf{T_F})$

Randomly move to a new location (make changes to the current answer for random search): $x_{n+1} = x_n +$ rand

Calculate $\Delta f = f_{n+1}(x_{n+1}) - f_n(x_n)$

(3) If the new answer is better, it will be accepted

Otherwise, a random number r is generated

If $p = \exp[-\Delta f/T] > 7$, the new answer will be accepted

Finish the loop

Update $x^* f^*$

$N = n + 1$

Finish the loop

3.5. Adjusting the Initial Parameters. First, we specify the parameters of the SA algorithm, which are checked based on parameter adjustment and trial and error, and these numbers are obtained, which are as follows:

Number of populations = 20

Popsize = 20

Number of iterations = 100

Maxiter = 100

Initial temperature = 100

$T0 = 100$

Final temperature = 1

$T_f = 1$

Cooling diagram = linear

$T_{\text{damp}} = ((T_0 - T_f)/\text{maxiter})$

Number of neighbors = 5

$N_n = 5$

4. Results

As it can be seen in Figure 1, iteration fatigue has a constant value of 20, and it can be concluded that the fatigue cost is optimized after this iteration.

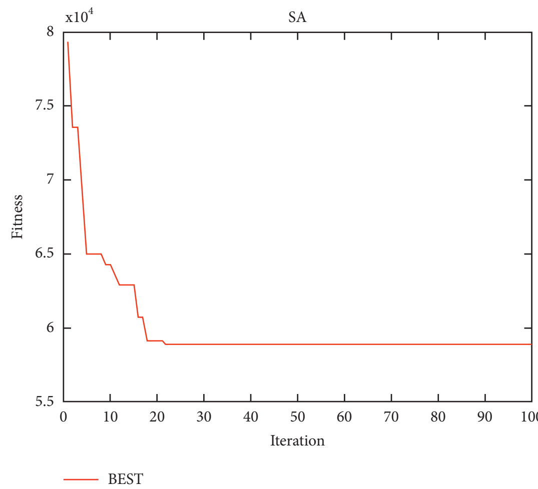

FIGURE 1: Performance of the simulated annealing algorithm for human resource scheduling.

TABLE 1: Number of working days.

i	j	k_1	k_2	k_3	k_4	k_5
1	1	0	0	0	1	0
1	2	0	1	0	0	1
1	3	1	0	1	1	0
1	4	0	0	0	0	1
2	1	0	0	0	0	1
2	2	0	0	1	0	0
2	3	0	1	0	0	0
2	4	1	1	0	1	0
3	1	1	1	1	0	0
3	2	0	0	0	1	0
3	3	0	0	0	0	1
3	4	0	0	1	0	0

TABLE 2: Results of the research.

Problem number	K, number of days	J, number of tasks	I, number of operators	DOR, degree of similarity of tasks	Best fitness objective (meta-heuristic	Optimal objective (mathematical)	ARE	Time
1	3	3	2	2	50,828	50,000	0.01	6.365
2	5	3	2	2	72,600.71	72,000	0.001	6.986
3	5	3	2	3	65,269.49	60,000	0.08	6.709
4	5	5	3	2	86,052.21	86,000	0.006	11.899
5	5	5	3	3	73,216.44	73,000	0.002	11.897

Now, we consider the final answer that i represents the number of operators and j represents the number of tasks, including geology, geophysics, petrophysics, and petroleum engineering tasks, and k represents the number of working days in Table 1.

According to the results of solving the model, it can be concluded that operator 1 does task 1 on day 4 and operator 1 does task 2 on day 2, and thus, the best human resource schedule was obtained with the least fatigue.

Efficiency meta-heuristic algorithms were also proposed to overcome the algorithmic complexity of the job rotation scheduling problem, and the quality of the SA algorithm was confirmed in this problem, which could encourage other researchers to use this algorithm at least to solve multiperiod allocation models with diverse applications. Since the proposed model creates new and flexible concepts for designing the job rotation scheduling problem, redefining and scrutinizing the concept of similarity of two tasks and costs due to fatigue and so on could add more and more real applications to the model. For this purpose, absolute relative error (ARE) $\text{mathematicalmodel} - \text{metahuristic}/\text{metaheuristic}$ has been used to accept the mathematical model. ARE has been recommended by Mahmoudi et al. [12]. When, between mathematical model output and meta-heuristic model, ARE is lower than 0.05, it means that the mathematical model can predict the behavior real system. Also, the results of the validation are shown in Table 2.

The results of investigating the model in problems with larger dimensions in the above-mentioned table show that by comparing rows 1 and 2, we conclude that with increasing days, the time to achieve the best objective function increases. By comparing rows 2 and 3, we conclude that with increasing DOR, that is, the number of days during which the degree of similarity of the tasks allocated to each operator is calculated, the time to achieve the best objective function decreases. By comparing rows 4 and 5, we conclude that with increasing DOR, that is, the number of days during which the degree of similarity of tasks allocated to each operator is calculated, the time to achieve the best objective function decreases. Also, the ARE value in the execution of all problems is calculated at less than 0.05 by comparing the two values of the objective function in the mathematical and meta-heuristic model. Therefore, it can be concluded that the meta-method will be able to solve problems on a large scale.

5. Managerial Insights and Practical Implications

According to the main advantages of the paper, it can be concluded that in the process of oil exploration management, in this paper, four tasks of geology, geophysics, petrophysics, and oil engineering were investigated, and it was concluded that the more similar the four tasks of exploration are, the higher the cost of human resource fatigue. Therefore, Naft-e-Khazar Company should avoid the employment of people in similar tasks in allocating its human resource to these four exploration tasks, and given that these four tasks are very similar in many sections, it should use job rotation among other tasks to prevent human resource fatigue and burnout.

6. Conclusion

In this study, a new and flexible model was provided that can be used to revolutionize scheduling tasks allocated to each operator during planning periods (called the job rotation scheduling problem) compared to other models. For this purpose, the paper develops a plan for the problem of job rotation scheduling to overcome workers' double fatigue. Therefore, this paper presents a nonlinear integer model that is proposed for the job rotation scheduling problem. It also suggests a new idea for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator. Results show that proposed model can calculate allocation costs, the fatigue cost could be included in job rotation scheduling, and decision efficiency could be developed. Finally, implemented simulated annealing meta-heuristic search algorithms to solve the problem, because the comparison of the mathematical model and the meta-heuristic model shows that the meta-heuristic model will be able to predict the behavior of the model in the long term. This research has a valuable contribution to achieving the management goals of the Naft-e-Khazar Company. Therefore, Naft-e-Khazar Company should avoid the employment of people in similar tasks in allocating its human resource to these four exploration tasks, and given that these four tasks are very similar in many sections, it should use job rotation among other tasks to prevent human resource fatigue and burnout. The main advantages of the research are as follows [9, 13–18]:

(i) A nonlinear integer model is proposed for the job rotation scheduling problem

(ii) A new idea is suggested for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator

(iii) The proposed model can calculate allocation costs; the fatigue cost could be included in job rotation scheduling; and decision efficiency could be developed

(iv) Simulated annealing meta-heuristic search algorithms will also be implemented to solve the model

Finally, a suggestion for further research is the development of the model taking into account uncertain parameters because, in the real world, systems are always faced with uncertainty.

Data Availability

The data used and the pseudocodes are included in the article. Codes are available upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Review Article

Evaluating Agile Practices in Green Supply Chain Management Using a Fuzzy Multicriteria Approach

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Ensuring the successful implementation of sustainable development goals in each country today depends heavily on the preservation and optimal use of its limited irreplaceable resources; therefore, a wide range of measures have been thus far taken by governments to deal with this issue. The study's main aim is to evaluate agile practices in green supply chain management utilizing a fuzzy multicriteria approach. To meet that aim, a quantitative research design was carried out by collecting data from fieldwork in the form of completing a questionnaire. Based on the results, the global spread of environmental standards along with the growing consumer demand for integrating green product supply into supply chain management (SCM), encompassing all practices associated with the flow of goods from the extraction and use of raw materials to delivery to end consumers as well as the flow of information throughout this chain, has accordingly given rise to the novel concept of green supply chain management (GSCM). Finally, GSCM criteria were identified and then prioritized, exploiting a fuzzy multicriteria approach in the present study.

1. Introduction

Green supply chain management (GSCM) emerged from the conventional supply chain management (SCM), wherein environmental compliance has been of utmost importance, aimed at reducing environmental pollution from different stages, namely, upstream to downstream, within the supply chain [1]. GSCM practices have thus developed into emerging activity-based management that can help improve competitiveness in the bioindustrial sector and even reflect on environmental actions and economic performance. Many studies have so far reported how GSCM practices can lead to a decline in the environmental burden of production operations and residues as well as an increase in the competitiveness of the industry [2]. GSCM also seeks to remove or lessen negative environmental impacts (namely, air, water, and soil pollution) and waste resources (namely, energy, materials, and products) from the extraction or exploitation of raw materials to the final consumption of products [3]. Thus, GSCM practices are assumed as key concepts, incorporating environmental thinking into product design, production process, raw material selection and sourcing, final product delivery, and life cycle SCM [4]. In this sense, Cao and Chen [5]reported that environmental issues such as greenhouse gas emissions, resource extraction and production, and reusing and recycling, arising from all product life cycle stages, can be implemented during specific activities at different levels, whose acceptance could lead to limited resources and reduce the environmental burden. Thus, GSCM practices are thought of as one of the major approaches to profitability, which help maximize market share and diminish destructive environmental risks and impacts [6]. The presence of several decision-making criteria affecting GSCM in numerous organizations along with the occurrence of multiple goals in the nature of this type of management has consequently made it a significantly challenging issue in decision theory, which should be considered in the literature of industrial engineering and operations management. In general, creating GSCM and paying much more attention to environmental issues can relegate costs, improve environmental performance, and strengthen the reputation of companies and organizations [3, 7].

Nevertheless, managers usually regard environmental management, sometimes even energy management, as a decelerating and costly factor, with no economic justification in this sense. Among the main principles from Chapter 8 of the Rio Declaration of 1992 is the effective use of economic instruments and market mechanisms as well as other incentives to realize sustainable development. Article 14 of Johannesburg Summit 2002—the World Summit on Sustainable Development—also emphasizes sustainable production and consumption policies in companies and organizations to attain this goal [8]. Considering environmental concerns, induced to new heights over the past decades, environmental pollution and SCM development must be addressed because such practices can play an important role in preventing the waste of financial, human, and time resources and even revolutionizing energy consumption structure in production/service industry. Operational solutions to this problem should be thus combined in the form of a comprehensive SCM approach [6].

Despite the increasing development and adoption of environmental management strategies in many mining companies worldwide, there are still some significant research topics on environmental issues, particularly GSCM practices. SCM has also turned into a common practice at the industry level and numerous articles on its theories and practices have been so far published, although the evaluation of supply chain performance has received little attention [7–12]. Overall, minimal effort has been made to systematically identify the evaluation criteria for supply chain performance. In addition, no consensus exists among researchers on the most appropriate method to prioritize such criteria [13–15].

The contributions of this study through the investigation of green supply chain management can be defined as follows:

(i) GSCM may help prevent the use of toxic and hazardous chemicals

(ii) The nature and advantages of GSCM can be applied to all parts of an organization

(iii) Supply chain greening can benefit companies and organizations at both individual and national levels

(iv) GSCM programs can provide particular competitive benefits, including lower costs, and greener products

2. Literature Review

2.1. SCM Theoretical Foundations. The term "supply chain" was first invented by Banbury in the mid-1970s and then applied to pass on electricity to the ultimate consumer. In the 1960–1970s, companies and organizations also sought to improve their competitiveness by standardizing and boosting their internal processes to produce better-quality and lower-cost products. The prevailing view at the time was that strong engineering and design, as well as coherent production operations, could be a prerequisite to meeting market demands and thus gaining more market share. For this reason, companies and organizations focused on augmenting efficiency. In the 1980s, with the wide variety of customer behavior patterns, companies and organizations became increasingly interested in expanding product line flexibility and developing new products to serve consumer needs. The 1990s was accordingly the period of improvement in the production processes and the exploitation of reengineering patterns. In order to keep their presence and multiply their market share, the leaders of many industries and factories also realized that developing internal processes and flexibility in the production process and increasing the quality and reducing the costs of raw materials were among the critical factors in achieving the above-mentioned goals. Over the last years of the second millennium and the start of the 21st century, successful companies and organizations correspondingly found that a new approach to SCM based on information technology (IT) was needed given the rapid development of IT in recent years and its widespread use around the world, so electronic commerce (e-commerce) could be the factor of their superiority in competitive markets [3, 10, 16, 17].

2.2. GSCM. In 1976, two American scholars asserted that some synthetic chemicals would damage the ozone layer. Scientific research also substantiated this theory and found evidence that ozone depletion was much faster than that proposed in some estimates and models. Considering the need to take measures to solve this problem and upon the call by the United Nations in 1985, the representatives of 21 countries, and the member states of the European Economic Community (EEC) met in Vienna, to talk about the global policy to fight against the destruction of the ozone layer. In 1987, the report of the World Commission on Environment and Development, known as the Brundtland Report, was published entitled "Our Common Future" and more than 50 world leaders supported it in 1988 [6, 17–19]. GSCM was thus introduced by the Michigan State University Industrial Research Association in 1996, as a novel management model for environmental protection. Here, GSCM from the perspective of the product life cycle included all stages of raw materials, product design and manufacturing, product sales and transfer, as well as product reusing and recycling. Exploiting SCM along with green technologies, companies and organizations could accordingly reduce the negative environmental impacts and achieve the preservation and optimal use of energy resources [20–22].

2.3. Green Approach to SCM. Following the spread of natural pollutants, much attention has been thus far paid to the negative impacts of development measures, including those associated with industries, managers, and governments. The milestone of many efforts in this respect can be seen in the approval of the Johannesburg Summit 2002. Therefore, green management seeks to reduce the negative consequences in the field of water, soil, air, climate, energy, and natural resources by using legal and cultural levers. Table 1 provides the summary of some environmental laws [23–26].

Sustainable SCM accordingly involves economic dimensions as well as environmental and social sustainability. For that reason, the concept of sustainable SCM is much broader than GSCM, which is merely one part of sustainable SCM. In the past, the product life cycle also encompassed processes from design to consumption, while it includes the processes of raw material preparation, design, construction, use and recycling, reusing, and the formation of a closed-loop material flow in the approach for environmental management to diminish resource consumption and harmful environmental impacts. GSCM also aims to change the traditional linear chain model from suppliers to users and then integrate recycling economics into SCM. By doing so, a closed-loop cyclic chain develops. If companies and organizations exploit GSCM, they can achieve relative success in terms of competitive advantages and resolve environmental problems. Furthermore, implementing GSCM can help avoid green barriers to global trade. Therefore, there is a need to move quickly toward implementing GSCM to seize much more opportunities, deal with some related challenges, and succeed.

3. Methodology

The present study with a quantitative research design was conducted by collecting data from fieldwork in the form of completing a questionnaire. In this way, according to the research topic and the main questions addressed to identify the criteria for GSCM practices in the mining industry, the related literature was reviewed, and then the criteria concerned were divided and organized. Afterward, based on the desired criteria, some items were summarized in a questionnaire in the form of pairwise comparison matrices. Upon preparing the questionnaire, it was distributed among managers and experts working in the field of the mining industry. After completing and collecting the questionnaires, the data were extracted, classified, and analyzed.

In this study, the statistical population consisted of experts who were among the most experienced people in the field of industry to evaluate GSCM practices in the mining industry. During the initial studies of the effective criteria, 37 experts working in the field of GSCM were selected. The expertise conditions in this research were having sufficient knowledge and at least ten years of work experience in this field along with a managerial position or specialization in GSCM with bachelor or higher degrees.

The questionnaire items were thus in two parts:

(A) The first part was an attempt to collect general and demographic characteristics information together with the history of work experience using general items.

(B) The second part contained specialized items in the form of pairwise comparison matrices to rank the criteria. After examining the available resources related to the evaluation of GSCM practices in the mining industry, Table 1 was drawn. Then, utilizing the factors given in Table 1, a research questionnaire was designed to weigh the key criteria affecting the evaluation of GSCM practices in the mining industry.

In order to check the validity of the given questionnaire using content validation methods, the items addressed were first reviewed by the experts and then the necessary corrections were made. As the data collection methods in the fuzzy multicriteria approach were established and the framework in this technique was specified, only some changes were made in the way of getting the responses and then the structure of the questionnaire was modified.

4. Results

Of the 11 subcriteria extracted in the former step, a survey matrix was prepared, so that the row items and column choices of this matrix consisted of the same subcriteria. The initial matrix was then provided to the experts as illustrated in the questionnaire and they were asked to numerically import the effect size of the row factors (A) on the column ones (B) between zero and four in the relevant cells via pairwise comparisons, and these numbers included the following concepts:

Zero (0): factor (A) has no effect on factor (B).

One (1): factor (A) has little effect on factor (B).

Two (2): factor (A) affects factor (B).

Three (3): factor (A) has a relatively large effect on factor (B).

Four (4): factor (A) has a strong effect on factor (B).

As emphasized in the questionnaire, the respected experts considered the following key points in the pairwise comparisons: first, rating only the direct relationship for the effect of row factors (A) on column ones (B) and not making a mistake due to a large number of matrix cells, so the inverse relationship meant the effect of column factors (B) on row ones (A) had not been taken into account, second, avoiding the indirect effect that row factor (A) had on column one (B) due to other factors in the problem because indirect effects automatically appeared in the final structure of the problem.

The matrices obtained from the second step were accordingly collected and the existence or nonexistence of a relationship between two factors was decided based on experts' consensus. If more than half of the group of experts had determined the effect size of a row factor (A) on column one (B) to be zero (0), it would confirm the effectiveness of the row factor (A). The same number of votes for a score greater than zero in a matrix cell could further prove the direct effect of row factor (A) on column one (B).

The median scores given by the experts were also directly related to the effect of the row subcriterion (A) on the

Table 1: GSCM criteria.

No.	Criteria	Subcriteria	References
1	Quality	Defect rate, commitment to quality management, warranty policies, abnormal quality achievement, the International Organization for Standardization (ISO) quality management system, quality assurance, corrective and preventive actions, process improvement	[5, 8–12]
2	Price	Suitability of material price to market price, shipping costs, product pricing, ordering costs	[5, 8–10, 12]
3	Technology	Technology readiness level, research and development (R&D) capability, current production facilities, supply chain technology development to meet current and future demands, technological compatibility, capacity, pollution prevention	[8–13]
4	Delivery	Order execution, warehouse management supplier, delivery reliability, appropriate delivery date, timeliness, product development skills, delay time, supplier flexibility	[5, 8–10, 13]
5	Environmental management	Environmental certification such as ISO 14000, ecoefficiency, the restriction of hazardous substances (RoHS) directive 2002/95/EC compliance, environmental protection program, environmental policy, continuous monitoring in compliance, green process planning system	[8, 11–15]
6	Pollution control	Air pollution, pollution control plan, water and wastewater, average volume of air pollutants, solid waste, release of harmful materials	[8, 9, 11, 15]
7	Green innovation	Green technologies, green process, production planning, renewable product design, product redesign, green design, product design, material recycling	[5, 8, 12, 13]
8	Hazardous material management	Hazardous material management, process audit, inventory of hazardous materials, prevention of material mix-up, ozone-depleting chemicals, harmful substance use	[5, 8, 11]
9	Green image	Ratio of green consumers to total consumers, materials used in components of supply to reduce impacts on natural resources, social responsibility, ability to change trends and products to reduce impacts on natural resources, stakeholder relations	[8–11, 13]
10	Green product	Recycling, disposal costs of components, green production, green packaging, green product certification, disposal, use of recycled and nontoxic materials	[8, 11]
11	Competencies	Distinctive competencies, decentralized decision-making, emphasis on core competence, trust-based relationships, team-oriented goals and criteria, incentive structures for innovation, vertical integration	[6, 16, 17]

column subcriterion (B) for each of the relationships endorsed in the previous step.

According to the third and fourth steps, an X matrix was formed. In this step, the corresponding diagram with the X matrix could be drawn as the initial one, so that its vertices were the same as the components of the system and its arc was equal to the degrees of direct relationships between both criteria of the system and the effect size of each direct relationship on the corresponding arc. Obviously, the effect size of zero (0) indicated the lack of a direct relationship in pairwise comparisons, and thus no arc was drawn for it (Table 2).

4.1. Matrix Formation. Each input in the X matrix was multiplied by the "inverse of the largest sum of the rows of that matrix (λ)" to obtain the X matrix, which represented the relative effect size of the direct relationships in the system (Table 3).

$$(M = \lambda * X). \tag{1}$$

4.2. S Matrix Formation. An S matrix was formed, which denoted the relative effect size of direct and indirect relationships (Table 4).

$$S = M(I - M)^{-1}. \tag{2}$$

5. Discussion

In the S matrix, the row sum of the entries (R), the column sum of the entries (J), the sum ($R+J$), and the difference ($R-J$) were calculated. The value (R) for each factor denoted the degree of the effect of that factor on other system factors and the corresponding value (J) showed the effect of the given factor on other system factors. Therefore, ($R+J$) could determine the sum of the effect of the desired factor in the system; in other words, the factor that had the highest value could have the most frequent interactions with other factors in the system (Figures 1–4). The final value of the effect of each factor on the sum of other system factors was additionally obtained from the difference ($R-J$), so:

If $R > J \longrightarrow R - J > 0$, then the factor involved had a definite effect size.

If $R < J \longrightarrow R - J < 0$, then the factor desired had a definite effect size.

Upon performing the calculations by the software, the values of (R), (J), ($R+J$), and ($R-J$) were also obtained according to Tables 5 and 6.

Best nonfuzzy performance (BNP) was further applied for fuzzy decoupling control purposes, as shown below.

$$\mathrm{BNP} = \frac{(u-l)+(m-l)}{3}. \tag{3}$$

By arranging the values of (R), (J), ($R+J$), and ($R-J$) in descending order, Tables 7 and 8 were obtained.

TABLE 2: The X matrix of the effect size governing direct relationships in the system in a fuzzy form.

	Quality C1	Price C2	Technology C3	Delivery C4	Environmental management C5	Pollution control C6	Green innovation C7	Hazardous material management C8	Green image C9	Green product C10	Competencies C11
C1	(0, 0, 0.25)	(0, 0.25, 0.25)	(0.25, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.25)	(1, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)
C2	(0, 0.25, 0.5)	(0.25, 0.5, 0)	(0.5, 0, 0)	(0, 0, 0.25)	(0, 0.25, 0.25)	(0.25, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.25)
C3	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0)	(0.75, 0, 0)	(0, 0, 0.25)	(0, 0.25, 0.25)	(0.25, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)
C4	(0.5, 0.75, 1)	(0.75, 1, 0.25)	(1, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0)	(0.75, 0, 0)	(0, 0, 0.25)	(0, 0.25, 0.25)
C5	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.25)	(1, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0)
C6	(0, 0.25, 0.5)	(0.25, 0.5, 0)	(0.5, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.25)	(0.5, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)
C7	(0, 0.25, 0.5)	(0.25, 0.5, 0.25)	(0.5, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.25)
C8	(0, 0.25, 0.5)	(0.25, 0.5, 0.25)	(0.5, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)
C9	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.25)	(1, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)
C10	(0, 0.25, 0.5)	(0.25, 0.5, 0.25)	(0.5, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.5)	(0.75, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 0.5)
C11	(0, 0, 0.25)	(0, 0.25, 0)	(0.25, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.25)	(0.5, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)	(0.75, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 0.25)

Table 3: The M matrix of the effect size governing direct relationships in the system in a normalized fuzzy form.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	(0, 0, 0.03)	(0, 0.03, 0.03)	(0.03, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)	(0.11, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)
C2	(0, 0.03, 0.06)	(0.03, 0.06, 0)	(0.06, 0, 0)	(0, 0, 0.03)	(0, 0.03, 0.03)	(0.03, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)
C3	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0)	(0.08, 0, 0)	(0, 0, 0.03)	(0, 0.03, 0.03)	(0.03, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)
C4	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)	(0.11, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0)	(0.08, 0, 0)	(0, 0, 0.03)	(0, 0.03, 0.03)
C5	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)	(0.11, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0)
C6	(0, 0.03, 0.06)	(0.03, 0.06, 0)	(0.06, 0, 0.03)	(0, 0.03, 0.06)	(0.03, 0.06, 0.03)	(0.06, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)
C7	(0, 0.03, 0.06)	(0.03, 0.06, 0.03)	(0.06, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)
C8	(0, 0.03, 0.06)	(0.03, 0.06, 0.03)	(0.06, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)
C9	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.03)	(0.11, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)
C10	(0, 0.03, 0.06)	(0.03, 0.06, 0.03)	(0.06, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.06)	(0.08, 0.06, 0.08)	(0.06, 0.08, 0.11)	(0.08, 0.11, 0.06)
C11	(0, 0, 0.03)	(0, 0.03, 0)	(0.03, 0, 0.03)	(0, 0.03, 0.06)	(0.03, 0.06, 0.03)	(0.06, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)	(0.08, 0.03, 0.06)	(0.03, 0.06, 0.08)	(0.06, 0.08, 0.03)

TABLE 4: The S matrix indicating the relative effect size of direct and indirect relationships in a fuzzy form.

	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$	$C7$	$C8$	$C9$	$C10$	$C11$
$C1$	(0.01, 0.05, 0.31)	(0.04, 0.12, 0.39)	(0.07, 0.16, 0.46)	(0.04, 0.14, 0.43)	(0.07, 0.15, 0.45)	(0.04, 0.13, 0.4)	(0.02, 0.11, 0.41)	(0.01, 0.09, 0.35)	(0.04, 0.13, 0.4)	(0.04, 0.13, 0.29)	(0.04, 0.11, 0.36)
$C2$	(0.01, 0.08, 0.33)	(0.01, 0.07, 0.33)	(0.04, 0.14, 0.42)	(0.07, 0.15, 0.45)	(0.04, 0.13, 0.41)	(0.04, 0.12, 0.39)	(0.04, 0.14, 0.42)	(0.04, 0.12, 0.36)	(0.04, 0.12, 0.39)	(0.04, 0.13, 0.28)	(0.01, 0.08, 0.34)
$C3$	(0.04, 0.11, 0.35)	(0.04, 0.13, 0.38)	(0.02, 0.08, 0.38)	(0.05, 0.14, 0.42)	(0.04, 0.14, 0.41)	(0.04, 0.13, 0.39)	(0.04, 0.14, 0.42)	(0.04, 0.12, 0.37)	(0.04, 0.13, 0.39)	(0.07, 0.15, 0.3)	(0.01, 0.09, 0.34)
$C4$	(0.07, 0.13, 0.39)	(0.04, 0.13, 0.39)	(0.05, 0.14, 0.44)	(0.02, 0.09, 0.39)	(0.05, 0.14, 0.43)	(0.04, 0.13, 0.41)	(0.07, 0.16, 0.46)	(0.04, 0.12, 0.38)	(0.04, 0.13, 0.41)	(0.04, 0.13, 0.3)	(0.01, 0.09, 0.35)
$C5$	(0.04, 0.11, 0.37)	(0.04, 0.13, 0.4)	(0.08, 0.16, 0.48)	(0.05, 0.15, 0.45)	(0.02, 0.09, 0.39)	(0.07, 0.15, 0.44)	(0.07, 0.16, 0.47)	(0.04, 0.12, 0.39)	(0.04, 0.13, 0.41)	(0.02, 0.11, 0.28)	(0.04, 0.12, 0.38)
$C6$	(0, 0.07, 0.31)	(0.01, 0.09, 0.33)	(0.04, 0.12, 0.39)	(0.04, 0.13, 0.39)	(0.04, 0.12, 0.38)	(0.01, 0.06, 0.31)	(0.04, 0.12, 0.39)	(0, 0.08, 0.32)	(0.01, 0.09, 0.34)	(0.04, 0.12, 0.26)	(0.03, 0.1, 0.33)
$C7$	(0.01, 0.09, 0.34)	(0.04, 0.13, 0.39)	(0.05, 0.14, 0.44)	(0.08, 0.16, 0.46)	(0.04, 0.14, 0.42)	(0.04, 0.13, 0.4)	(0.02, 0.08, 0.38)	(0.04, 0.12, 0.38)	(0.04, 0.13, 0.4)	(0.07, 0.15, 0.31)	(0.03, 0.12, 0.37)
$C8$	(0.01, 0.08, 0.33)	(0.04, 0.12, 0.38)	(0.04, 0.14, 0.42)	(0.04, 0.14, 0.42)	(0.04, 0.13, 0.41)	(0.04, 0.12, 0.39)	(0.04, 0.13, 0.41)	(0.01, 0.06, 0.32)	(0.07, 0.14, 0.41)	(0.04, 0.13, 0.28)	(0.01, 0.08, 0.34)
$C9$	(0.04, 0.11, 0.36)	(0.04, 0.13, 0.38)	(0.07, 0.16, 0.46)	(0.05, 0.14, 0.43)	(0.04, 0.14, 0.41)	(0.01, 0.1, 0.38)	(0.04, 0.14, 0.42)	(0.04, 0.12, 0.37)	(0.01, 0.07, 0.35)	(0.04, 0.13, 0.29)	(0.03, 0.11, 0.36)
$C10$	(0.01, 0.08, 0.33)	(0.04, 0.12, 0.37)	(0.04, 0.13, 0.42)	(0.07, 0.15, 0.45)	(0.07, 0.15, 0.43)	(0.01, 0.09, 0.37)	(0.07, 0.15, 0.44)	(0.01, 0.09, 0.34)	(0.01, 0.09, 0.37)	(0.01, 0.07, 0.23)	(0.01, 0.08, 0.33)
$C11$	(0.01, 0.05, 0.27)	(0.01,0.08, 0.32)	(0.04, 0.12, 0.37)	(0.04, 0.12, 0.37)	(0.04, 0.12, 0.36)	(0.04, 0.11, 0.35)	(0.04, 0.12, 0.37)	(0.01, 0.08, 0.31)	(0.04, 0.11, 0.35)	(0.01, 0.09, 0.23)	(0, 0.05, 0.27)

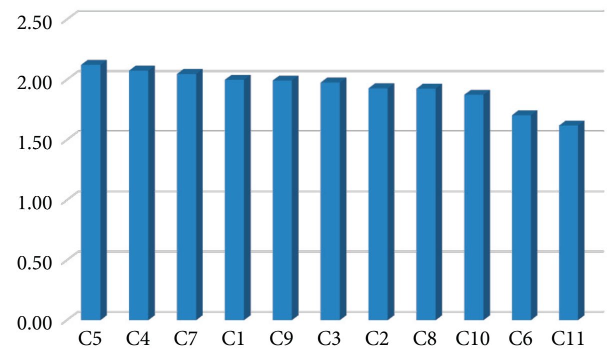

Figure 1: The impact of criteria.

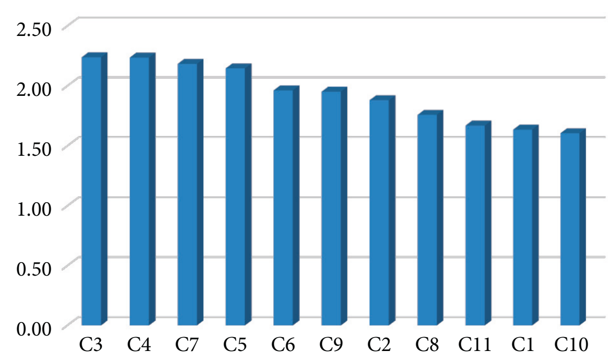

Figure 2: The effectiveness of criteria.

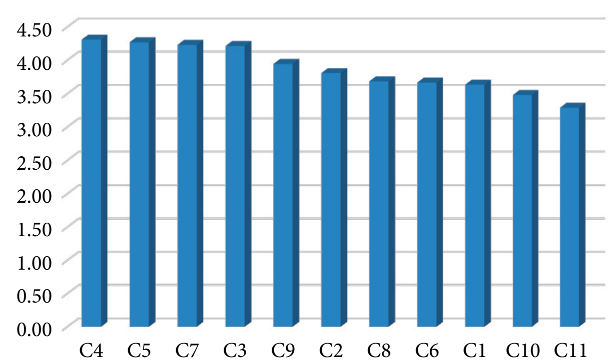

Figure 3: The sum of impact and effectiveness of criteria.

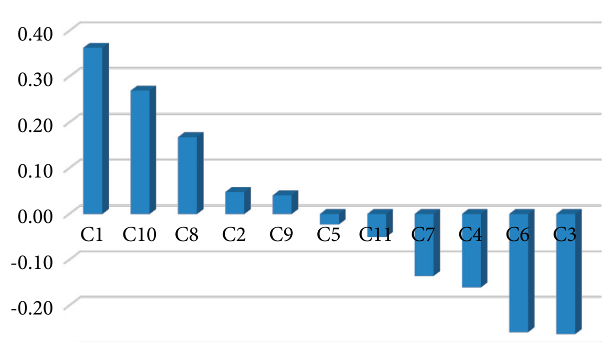

Figure 4: Difference between impact and effectiveness of criteria.

5.1. Final Classified Diagram Formation. A Cartesian coordinate system was initially established so that its longitudinal axis was calibrated in terms of values $(R+J)$ and its transverse axis was scaled with regard to $(R-J)$, and then the position of each of the existing criteria with a point in the coordinates "A: $(R+J,\ R-J)$" was specified on this system. The following diagram represents a simple view of the final structure of the system (Figure 5).

5.2. Final Ranking of Subcriteria with respect to $(R+J)$ and $(R-J)$. Although experts' judgments during pairwise comparisons are assumed simple and demand no knowledge of how the decision-making trial and evaluation laboratory (DEMATEL) works, the quality of their views on various aspects of an issue is very influential and thus provides sufficient information on it. For one problem, the DEMATEL method can be accordingly replicated several times and a proper structure can be completed by reviewing and revising the criteria of a system and their effect size. Other than the dependencies of the resulting weights (for the subcriteria) in expert opinions, such dependencies can be relative and obtained only with respect to the assumed criteria within the model but the effectiveness of each criterion of other factors outside the system is not taken into consideration. According to the information retrieved from the implementation of the preceding steps, the subcriteria in this study were ranked in terms of $(R+J)$ and $(R-J)$ in this section.

Green attitudes in companies and organizations along with the development of organizational structures called "green assurance" have thus far replaced organizational units including quality assurance. Supply chain greening accordingly refers to the process of reflecting on environmental criteria or considerations throughout SCM. GSCM can thus integrate SCM with environmental requirements into all stages of product design, raw material selection and supply, production and manufacturing, distribution and transfer processes, customer delivery, and finally, consumption services as well as recycling and reusing management to maximize the efficiency of energy resources and improve the performance of the entire supply chain. During the studies of the environmental impacts of SCM practices, the effects of products on the environment are often analyzed using a holistic approach (including the product life cycle from the onset to the end). Within this approach, all the ecological effects (namely, the examination of habits and lifestyles of creatures and their interactions with the environment) of each activity at different stages of the product life cycle, such as product concept, design, preparation of raw materials, production and manufacturing, assembly, storage, packaging, product transfer, and recycling and reusing are further measured and included in the product design.

GSCM has been accordingly recognized as one of the successful strategies to gain competitive advantages in manufacturing companies and organizations in recent years thanks to the benefits of cost reduction and innovation strategies in product manufacturing (namely, differentiation

Table 5: Values (J), (R), ($R+J$), and ($R-J$) in a fuzzy form.

	R	J	$R+J$	$R-J$
C1	(0.42, 1.33, 4.25)	(0.22, 0.98, 3.71)	(0.64, 2.3, 7.96)	(0.19, 0.35, 0.54)
C2	(0.38, 1.29, 4.11)	(0.34, 1.25, 4.05)	(0.72, 2.54, 8.17)	(0.04, 0.04, 0.06)
C3	(0.42, 1.35, 4.16)	(0.54, 1.5, 4.68)	(0.95, 2.85, 8.84)	(−0.12, −0.14, −0.53)
C4	(0.46, 1.4, 4.36)	(0.54, 1.5, 4.66)	(1, 2.9, 9.02)	(−0.08, −0.1, −0.3)
C5	(0.5, 1.44, 4.44)	(0.49, 1.45, 4.49)	(0.99, 2.89, 8.93)	(0, −0.01, −0.06)
C6	(0.25, 1.11, 3.75)	(0.38, 1.28, 4.22)	(0.63, 2.39, 7.98)	(−0.13, −0.18, −0.47)
C7	(0.46, 1.39, 4.3)	(0.51, 1.45, 4.59)	(0.97, 2.84, 8.88)	(−0.05, −0.06, −0.29)
C8	(0.38, 1.29, 4.11)	(0.26, 1.12, 3.89)	(0.64, 2.41, 7.99)	(0.12, 0.17, 0.22)
C9	(0.42, 1.35, 4.2)	(0.37, 1.28, 4.21)	(0.79, 2.63, 8.41)	(0.05, 0.08, 0)
C10	(0.35, 1.19, 4.08)	(0.43, 1.33, 3.05)	(0.78, 2.52, 7.14)	(−0.08, −0.14, 1.03)
C11	(0.26, 1.05, 3.56)	(0.21, 1.04, 3.76)	(0.46, 2.08, 7.32)	(0.05, 0.01, −0.2)

Table 6: Values (J), (R), ($R+J$), and ($R-J$) in a nonfuzzy form (definite).

	R	J	$R+J$	$R-J$
C1	2.00	1.64	3.63	0.36
C2	1.93	1.88	3.81	0.05
C3	1.98	2.24	4.21	−0.26
C4	2.07	2.24	4.31	−0.16
C5	2.12	2.15	4.27	−0.02
C6	1.70	1.96	3.67	−0.26
C7	2.05	2.18	4.23	−0.14
C8	1.93	1.76	3.68	0.17
C9	1.99	1.95	3.94	0.04
C10	1.87	1.60	3.48	0.27
C11	1.62	1.67	3.29	−0.05

Table 7: The order of impact and effectiveness of subcriteria in relation to each other.

Priority	Impact	R	Priority	Effectiveness	J
1	C5	2.12	1	C3	2.24
2	C4	2.07	2	C4	2.24
3	C7	2.05	3	C7	2.18
4	C1	2.00	4	C5	2.15
5	C9	1.99	5	C6	1.96
6	C3	1.98	6	C9	1.95
7	C2	1.93	7	C2	1.88
8	C8	1.93	8	C8	1.76
9	C10	1.87	9	C11	1.67
10	C6	1.70	10	C1	1.64
11	C11	1.62	11	C10	1.60

Table 8: The order of the final impact of subcriteria on other subcriteria and their final importance in the system.

No.	Weight priority based on interaction	$R+J$	No.	Priority based on net impact/effectiveness intensity	$R-J$	
1	C4	4.31	1	C1	0.36	
2	C5	4.27	2	C10	0.27	
3	C7	4.23	3	C8	0.17	Impact criteria ($R-J>0$)
4	C3	4.21	4	C2	0.05	
5	C9	3.94	5	C9	0.04	
6	C2	3.81	6	C5	−0.02	
7	C8	3.68	7	C11	−0.05	
8	C6	3.67	8	C7	−0.14	Effective
9	C1	3.63	9	C4	−0.16	criteria ($R-J<0$)
10	C10	3.48	10	C6	−0.26	
11	C11	3.29	11	C3	−0.26	

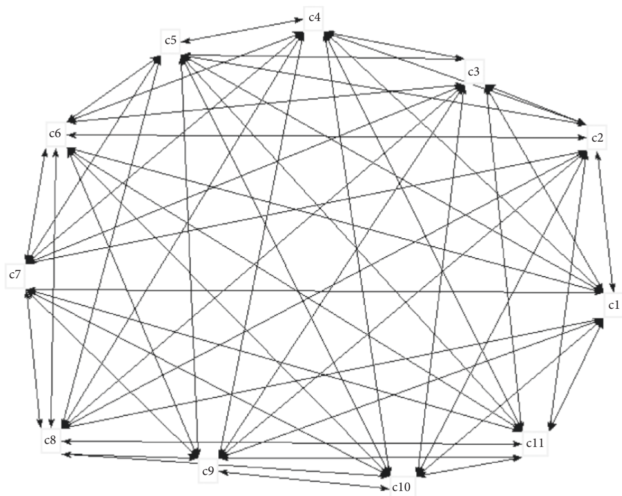

Figure 5: Final classified diagram.

strategy). GSCM can also lead to the faster delivery of goods and services, reduce inactivity, lower costs, increase quality, and even give rise to competitive advantages by creating more value-added for consumers following the supply of green products. Moreover, GSCM seeks to change the traditional linear chain model from suppliers to users and then integrate recycling economics into SCM. By doing so, a closed-loop cyclic chain develops. If companies and organizations exploit GSCM, they can achieve relative success in terms of competitive advantages and deal with environmental problems. Furthermore, implementing GSCM can help avoid green barriers to global trade. Therefore, there is a dire need to move quickly toward implementing GSCM to seize much more opportunities, tackle some related challenges, and succeed. Various large companies, such as General Motors Co., Hewlett-Packard, Procter and Gamble Co., Nike Inc., and many others, have thus developed a good reputation and brand image for green products through GSCM research and implementation. In recent centuries, the need to evaluate and select technologies to minimize the destructive effects of manufacturing activities in various industries on the environment is also rising in such a way that industrial development has given way to sustainable development.

Optimizing production devices and hardware in order to boost efficiency and moderate environmental pollution should be thus considered. The utilization of new technologies and more scientific production line design can also diminish production waste as well as defective products. The use of advanced and high-tech devices can even lead to less depreciation.

Here, reverse logistics includes the process of returning goods and dealing appropriately with such items to increase the efficiency and profitability of logistics organizations. On the other hand, the impact and effectiveness of manufacturers, suppliers, and customers thanks to these interactions, which are ultimately determined by quality, production time, product delivery time, customer satisfaction, and cost reduction, have made reverse logistics a big goal for all existing companies and organizations working with SCM. In general and traditionally, producers do not assume any responsibilities for their goods, after distribution and consumption by consumers, and do not even give a positive response to any obligations for their distributed and consumed products. However, today, the volume of products manufactured and consumed has caused considerable damage to the environment and everyone, including consumers and officials, is concerned about their environment, as highlighted in many studies [17].

Waste management and the preparation and enactment of laws on waste products have further led commodity producers to improve the production process. As disposing of waste and cleaning the environment cost a fortune, this strategy can be thus an optimal way to develop GSCM, as mentioned in Lin [18].

Besides, innovation strategy can be very effective in gaining a competitive advantage as it has been used by manufacturing companies and organizations in recent years. Companies and organizations adopting these strategies for GSCM can also try to exploit differentiation strategies and reduce the costs of environmental degradation by innovating in the design and production of green and recyclable products. The simultaneous combination of both strategies can accordingly bring a competitive advantage to most companies and organizations, as confirmed in Mageto [17].

Factories also manufacture their products with an environmental approach using an efficiency-based strategy and can consequently achieve greater operating profit. This requires better partnership and commitment between consumers and suppliers. The environmental benefit of this strategy is that it diminishes waste and thus resource use. This strategy also demands a more comprehensive specialized environment compared with that employed in a risk-based strategy, which was consistent with the results reported by Tseng and Chiu [19].

The finished product should be also in the direction of establishing GSCM. To fulfill this, manufactured products can be designed, produced, and presented in such a way that they consume less energy or at least make use of new and clean alternatives. The objective realization of this case can be thus observed in the production of fuel-efficient cars from Japan and the high popularity of this product among Americans, as mentioned in the study by Sarkis et al. [20].

Being green should be thus found in the whole SCM. Therefore, in each part, it must receive materials and components with the highest levels of environmental compatibility. Without this integration, GSCM establishment is practically impossible. In other words, better results can be merely achieved if greening is considered as supply chain integration. Otherwise, the output of one loop may become green for the next loops, for which this output is an input, but not green for the entire supply chain and fail to develop GSCM, in line with the results reported by Zhu et al. [12].

In terms of providing services and products, there is a need to have the production cycle with the highest percentage of output accuracy and health. Here, a percentage means that better basic facilities have been employed, which was in agreement with the establishment of GSCM because more errors in output products could mean the waste of basic facilities, wherein raw materials in many cases were normal and their waste is contrary to GSCM principles. Defects and breakdowns in the output product, in addition to the waste of raw materials, can also lead to the loss of various driving forces, using many natural materials for their production, which was consistent with the findings by Zhu et al. [12].

All products must be additionally returnable to the production line and even recyclable. If the output product is not reversible and repairable in case of failures in practice, its components and healthy parts may be wasted and eventually cause the waste of raw materials and manufacturing energies, as supported in the results of the research by Tseng et al. [21]. This recovery system should be accordingly designed so that the products are recycled after depreciation and inefficiency with a high percentage and some parts become the materials used in the industry, as confirmed in Zhu et al. [12].

All the items mentioned in this section can be fulfilled if training is fulfilled, especially in the human resources, having a big share in compliance with GSCM. Besides, R&D is of utmost importance because production and technology used to establish GSCM would not be accomplished without them, which was in line with the findings by Sarkis et al. [20].

6. Conclusion

In short, GSCM may associate the prevention of the use of toxic and hazardous chemicals or the reduction of pollutants or waste release into the environment. Although these are essential, the nature and benefits of GSCM can be applied to all parts of an organization, and its effects can extend to all tangible and intangible areas. Supply chain greening can also bring benefits to companies and organizations at both individual and national levels. At the individual level, GSCM programs can provide certain competitive advantages, such as lower costs, greener products, and better integration with suppliers, create markets for products, and help suppliers adapt better to environmental issues at the national level. Greening SCM can thus improve the competitive position of companies and organizations by reducing costs.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare there are no conflicts of interest.

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Research Article

Presenting a Management Model for a Multiobjective Sustainable Supply Chain in the Cellulosic Industry and Its Implementation by the NSGA-II Meta-Heuristic Algorithm

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In recent years, with changing conditions in global markets and competition between supply chains, organizations have realized that in order to grow and survive in today's turbulent environment, they must make every effort to create and maintain a sustainable competitive advantage. Therefore, in this research, a multiobjective, multilevel, multiperiod, and multicommodity mathematical model is presented. The proposed model has five levels in the direct direction and three levels in the reverse direction. This research is one of the few studies that has considered the sustainable closed-loop supply chain of cellulosic-based products (paper and corrugated board) in the model and has considered it at all levels of the chain. Also, the quality of returned products in the reverse supply chain and its impact on the collection and recycling of products and returning to the supply chain are other contributions of this research. The results show, by increasing the transportation costs, the number of established distribution centers increases to a certain extent and finally remains constant. As it is shown, the reduction of transportation costs to the point of establishing four centers in the recession scenario and five centers in the boom scenario becomes saturated and is no longer able to minimize the number of established centers.

1. Introduction

Nowadays, one of the main concerns of organization managers and business owners is to improve and promote productivity and reduce costs [1]. Companies and organizations must provide resources to carry out the main processes of manufacturing and service provision. If they can establish a successful strategy and reduce their organization's supplying costs, their profitability will increase [2, 3]. This increase in profit margins increases with decreasing costs. As it is known, manufacturing and operation costs and also the purchase, supply, and logistics costs are the main costs [4]. The supply chain or logistics includes the physical part of the supply chain and mainly consists of all activities related to the flow of materials and products from the stage of raw material supply to the manufacturing of the final product, including transportation, warehousing, etc. [5]. One of the new trends in logistics management is reverse logistics and closed-loop supply chain [6]. The reverse supply chain represents a new vision of the supply chain in the form of supply chain management [7, 8]. Numerous reasons such as sustainable development, environmental concerns, energy shortages, shortage of natural resources, and issues such as reuse of defective products, reducing the costs of returned products, and improving the company's reputation have increased the attention span toward reverse chain management [9, 10]. Recycling or reuse of products as a scientific strategy is at the first level of urban management in developed countries [11]. In reverse logistics, products that reach the end of their useful life are repurchased from the end consumer, and after disassembly, the reusable parts of the product return to the life cycle in the form of scrapped products [12]. In fact, one of the essential tasks for an organization to be able to recycle its products is to set up its reverse supply chain. Designing and implementing a reverse logistics network for returned products not only reduce inventory and transportation costs but also increase customer loyalty [13, 14]. In general, decision-making in the supply chain is carried out in two forms, centralized and decentralized (which is the subject of discussion in this research).

In this study, a closed-loop supply chain including supplier, producer, distributor, and customer in the direction of the path and including burial center, collection center, and recycling center in the reverse path is considered. Suppliers are responsible for supplying raw materials to producers. Produced products are stored in warehouses and then sent to distributors. Finally, the final products are delivered to customers. In the reverse supply chain, used and discarded products are delivered from customers and sent to the collection center. At this stage, the products are differentiated based on quality. Paying attention to the quality of return products is one of the contributions of this research. Recycled products are sent to the recycling center and discarded products to the burial center. Also, some products are directly sent to producers based on their quality.

Research questions include the following:

(i) What is the production of cellulosic products in the conditions of recession and market boom?

(ii) How can the sides of stability in the supply chain be customized in the cellulosic products' industry?

The innovations of this research include the following:

(i) Paying attention to the quality of manufactured products and quality uncertainty in products

(ii) Considering cellulosic products in the closed loop and discussing stability

(iii) Paying attention to supply chain uncertainty using defined scenarios including recession and market boom

(iv) Paying attention to the fact that the model is multiperiod and multiproduct

(v) Paying attention to considering the sides of stability in the proposed closed-loop supply chain so that the economic, social, and environmental aspects are simultaneously considered

(vi) Paying attention to the customization of the proposed model for a real case study in the cellulosic products' industry

2. Literature Review

In their research, Zhu [15] presented an integrated multiobjective model for location considering transportation and determining the amount of inventory needed. Their proposed model was a two-level Stackelberg model and was implemented for a case study. Their objectives were as follows: (a) minimizing the related costs and (b) minimizing the resulting risk, which were expressed as minimizing the average distance between established centers. The model was examined in four different cases, the combination of the presence or absence of constraints on the number of new centers and the presence or absence of previously established centers.

Habibi et al. [16] considered the distribution problem under uncertainty in two stages. First, they solved the inventory and then the allocation in such a way as to minimize the total cost, and then, they used a two-stage heuristic algorithm to solve it. In the first stage, clustering was performed and the distribution was determined based on that, and in the second stage, a heuristic algorithm was used for allocation.

Tabrizi et al. [17] located distribution centers under uncertainty. Considering the failure of some points and lack of access to some points is among the contributions of this research. It was assumed that people travel to different points for relief. The methods of genetic meta-heuristic, simulated annealing, and memetic algorithm were used to solve the proposed model. Amiri et al. [18] presented a multistage model for distribution, routing, and inventory control under uncertainty. Minimizing service time, the cost of establishing relief centers and inventory costs were among the objectives of this study. The proposed MILP model was solved using epsilon-constraint and genetic algorithms for 30 different examples.

Roshanahad et al. [19] presented a new mathematical model for temporary production planning. Considering the penalty cost for environmental impacts was one of the contributions of this research. By increasing time, these penalties also increased. The objective of this study was to reduce costs under different scenarios.

Govindan et al. [20] presented a multiobjective, multiperiod, and multiproduct mathematical model for the allocation of distribution centers and warehouses. In the first phase of this research, strategic decisions were made such as the location and establishment of distribution centers, and in the second phase, operational decisions were made such as routing, determining the reliability of routes, and observing the time window of each route. Considering the split delivery was one of the contributions of this research. The proposed model was finally solved by NSGA-II and MOPSO metaheuristic algorithms.

Iqbal et al. [21] presented a mathematical model for the green chain. The main purpose of the proposed nonlinear and three-level mathematical model is to minimize costs in the green chain. The results show that the proposed model was able to increase system efficiency by 98.4%

Mohtashami et al. [22] presented a model in the set of green and inverse supply to reduce energy consumption and minimize the environmental environment. Considering the queuing system with limited resources in this research is one of its innovations. Minimizing transportation costs and the costs of environmental degradation is the most important goal of this study. We used to solve the proposed model in comparison with the genetic algorithm. Dong et al. [23] proposed a mathematical model for closed-loop supply chain management considering random demand and the reproduction system. Their proposed model had three objectives, including the following: 1- determining the manufacturers that have the most profit channel, 2- allocating distributors to customers, and 3- examining the flow between supply chain levels. The results of the case study showed that by increasing transportation costs, the costs of the whole system exponentially increase.

Wu [24] designed a dynamic competitive game in the closed-loop supply chain. Considering government involvement in the proposed supply chain is one of the innovations of this research. Therefore, the government has proposed six different strategies for the chain management. The Nash equilibrium approach has been used for this purpose. Minimizing environmental costs is one of the most important goals of the research. The results show the proper performance of the proposed model in minimizing the proposed supply chain costs. Table 1 categorizes the literature review.

According to the literature review, it can be said that this research is one of the few studies that has considered the sustainable closed-loop supply chain of cellulosic-based products (paper and corrugated board) in the model and has considered it at all levels of the chain. Also, the quality of returned products in the reverse supply chain and its impact on the collection and recycling of products and returning to the supply chain are other contributions of this research. The literature shows that there have been few studies that have considered all of the above issues in supply chain design. Therefore, the research gap is as follows: 1- lack of attention to the quality of manufactured products and quality uncertainty in products, 2- lack of attention to considering cellulosic products in the closed loop and sustainability issue, 3- lack of attention to considering uncertainty in the supply chain using defined scenarios including market recession and boom, 4—lack of attention to the multiperiod and multiproduct model, 5—lack of attention to sustainability in the proposed closed-loop supply chain so that the economic, social, and environmental aspects would be simultaneously considered, and 6-lack of attention to the customization of the proposed model for a real case study in the cellulosic products' industry.

3. Problem Statement

The main purpose of this model is to determine the flow of raw materials sent from suppliers to producers and to determine the amount of products produced and shipped to distributors and customers. Also, the flow of returned products from customers to collection centers and from collection centers to burial centers and recycling centers is examined.

Also, two scenarios of recession and boom have been considered in this study and the amount of products sent in conditions of recession and boom is compared with each other. The probability of occurrence of each scenario in this study is assumed to be the same. In the first scenario, the demand is very low, and in the second scenario, the demand is very high. The main goal of the model is to minimize supply chain costs while minimizing the environmental impact. Minimizing social responsibility risks is also one of the other goals of the research. Figure 1 shows the proposed supply chain.

3.1. Model Assumptions

(i) Demand for each product (cellulosic products) is not assumed as known in each stage, and the uncertainty considered in the model is scenario-based.

(ii) Space for storing demand for each manufactured cellulosic product is limited and predetermined.

(iii) The model is multiproduct, multiperiod, and multilevel.

(iv) Burial centers, collection centers, distributors, and recycling centers are located. The location is considered discrete, and the centers are selected from the candidate points.

3.1.1. Indices

e-Burial and disposal centers $e \in E$

g-Collection centers $g \in G$

d-Distributors $d \in D$

b-Recycling centers $b \in B$

l-Customers $l \in L$

n-Suppliers $n \in N$

m-Manufacturers $m \in M$

t-Period $t \in T$

q-Product quality q1,q2,... Q,

c-Products $c \in C$

s-Scenarios $s \in S$

3.1.2. Parameters

li_n Capacity of the center n

li_m' Capacity of the center m for the recovery of products

li_e Capacity of the center e

li_m Capacity of the center m

li_g Capacity of the center g

li_b Capacity of the center b

li_d Capacity of the center d

cb_e'' The amount of CO2 released to establish the center e

cb_g' The amount of CO2 released to establish the center g

cb_b'' The amount of CO2 released to establish the center b

cb_d The amount of CO2 released from transporting a unit of product per distance unit

cpk The cost of establishing the center e

h_d'' The cost of establishing the center p

h_p'' The cost of establishing the center g

h_g' The cost of establishing the center d

Table 1: Literature review.

	Author	Mathematical model	Single objective	Multi objective	Multilevel	Closed loop	Sustainability supply chain	Quality of products	Several products	Transportation	Multi capacity	Uncertainty	Market scenarios	Case study	Exact methods	Meta-heuristic
1	Dong et al. [23]	*	*		*	*			*			*		*	*	
2	Diabet et al. [25]	*		*	*									*	*	
3	[22]	*		*	*	*			*		*	*			*	
4	[26]	*		*	*	*		*	*			*			*	
5	[21]	*	*		*	*			*			*				*
6	[20]	*		*	*					*		*			*	
7	[19]	*		*	*	*	*		*	*	*	*				*
8	[18]	*	*		*	*			*			*			*	
9	[17]	*		*	*	*	*		*			*				*
10	[16]	*	*		*					*		*			*	
11	[15]	*		*	*	*	*	*		*	*				*	
12	This research	*		*	*	*	*	*	*	*	*	*	*	*	*	*

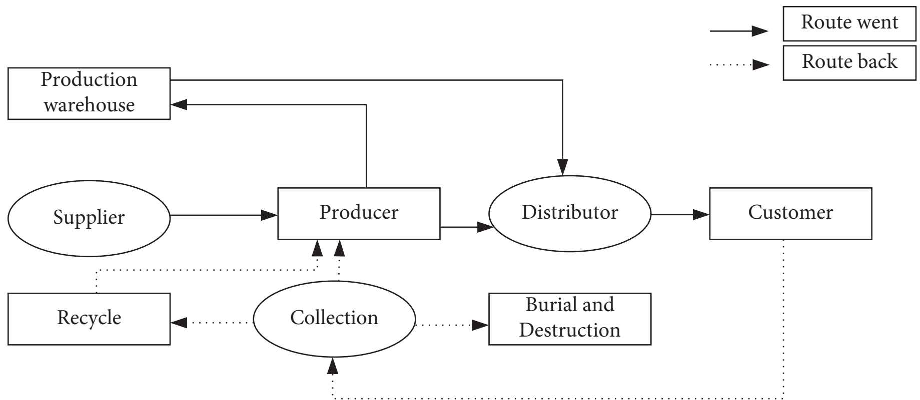

FIGURE 1: Proposed supply chain structure.

h_{d} The amount of CO2 released from transporting a unit of product per distance unit

vl_{cs} The value of product c in scenario s after recycling

d_{ls}^{ct} Demand of product c by customer l during period t in scenario s.

fo_{cs} The cost of manufacturing a unit of product c in scenario s.

$f\prime o_{cs}$ The cost of collecting a unit of product c in scenario s.

pg_{cq}^{s} The price of returned product c with quality q in scenario s

d_{gmqs}^{c} Cost/distance of transporting product c from center g to center m with quality q in scenario s

d_{nms}^{c} Cost/distance of transporting product c from center n to center m in scenario s

d_{mds}^{c} Cost/distance of transporting product c from center m to center d in scenario s

d_{lgs}^{c} Cost/distance of transporting product c from customer l to center g in scenario s

d_{gbqs}^{c} Cost/distance of transporting product c from center g to center b with quality q in scenario s

d_{geqs}^{c} Cost/distance of transporting product c from center g to center e with quality q in scenario s

d_{bmqs}^{c} Cost/distance of transporting product c from center b to center m with quality q in scenario s

d_{dls}^{c} Cost/distance of transporting product c from center d to customer l in scenario s

pr_s: The probability of occurrence of scenario s

$r_{l,q,s}^{ct}$ The return rate of product c with the quality level q from the customer center l during period t in scenario s

rr'^{ct} The return rate of product c from the collection center to the burial center during period t

rr^{ct} The return rate of product c from the collection center to the manufacturer during period t

rr''^{ct} The return rate of product c from the collection center to the recycling center during period t

pol_{dt} The total amount of pollution emitted during the establishment of the center d during period t

pol_{gt}' The total amount of pollution emitted during the establishment of the center g during period t

pol_{bt}'' The total amount of pollution emitted during the establishment of the center b during period t

pol_{et}'' The total amount of pollution emitted during the establishment of the center e during period t

3.1.3. Variables

x_{d}-If center d is established, 1, and otherwise, 0

x_g-If center g is established, 1, and otherwise, 0

x_b-If center b is established, 1, and otherwise, 0

x_e-If center e is established, 1, and otherwise, 0

z_{gmqs}^{ct}-The amount of product c sent from the center g to the center m with quality q during period t in scenario s

z_{mds}^{ct}-The amount of product c sent from the center m to the center d during period t in scenario s

z_{dls}^{ct}-The amount of product c from the center d to the customer l during period t in scenario s

z_{bmqs}^{ct}-The amount of product c sent from the center b to the center m with quality q during period t in scenario s

z_{mds}^{ct}-The amount of product c sent from the center m to the center d during period t in scenario s

z_{lgqs}^{ct}-The amount of product c sent from the customer l to the center g with quality q during period t in scenario s

z_{geqs}^{ct}-The amount of product c sent from the center g to the center e with quality q during period t in scenario s

z_{nms}^{ct}-The product c sent from the center n to the center m during period t during scenario s

z_{gbqs}^{ct}-The amount of product c sent from the center g to the center b with quality q during period t in scenario s

$$\min z1 = \left(\sum_{d\in D} h_d x_d + \sum_{g\in G} h_g' x_g + \sum_{b\in B} h_b'' x_b + \sum_{e\in E} h_e'' x_e\right)+,$$

$$+ pr_s\left(\sum_t \sum_s \left(\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} d^c_{nms} z^{ct}_{nms} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx^{st}_{jks} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d^c_{dl\ ,s} z^{ct}_{dls}\right.\right.$$

$$+ \sum_{s\in S}\sum_{t\in T}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^c_{\mathrm{lgs}} z^{ct}_{\mathrm{lgs}} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^c_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^c_{geqs} z^{ct}_{geqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^c_{gmqs} z^{ct}_{gmqs}\right.$$

$$\left. + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^c_{bmqs} z^{ct}_{bmqs}\right)$$

$$+ \sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} fo_{cs}.z^{ct}_{mds} + \sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} fo_{cs}'\left(\left(\sum_{g\in G}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{g\in G}\sum_{e\in E} z^{ct}_{geqs} + \sum_{g\in G}\sum_{m\in M} z^{ct}_{gmqs}\right)\right)$$

$$M\inf_2 = LM + LP,$$

$$LM = \sum_{b\in B} x_b.cb_b'' + \sum_{g\in G} x_g.cb_g' + \sum_{e\in E} x_e.cb_e'' + \sum_{d\in D} x_d.cb_d,$$

$$LP = \sum_{s\in S} w_{sen}.\sum_{t\in T} CEM\left[\sum_t\sum_s\left(\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} d^c_{nms} z^{ct}_{nms} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx^{st}_{jks} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d^c_{dl\ ,s} z^{ct}_{dls}\sum_{s\in S}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^c_{\mathrm{lgs}} z^{ct}_{\mathrm{lgs}}\right.\right.\right.$$

$$\left.\left.\left. + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^c_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^c_{geqs} z^{ct}_{geqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^c_{gmqs} z^{ct}_{gmqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^c_{bmqs} z^{ct}_{bmqs}\right)\right)\right]$$

$$M\inf 3 = \sum_{t\in T}\sum_{d\in D} pol_{dt}.x_d + \sum_{g\in G}\sum_{t\in T} pol_{gt}'.x_g + \sum_{b\in B}\sum_{t\in T} pol_{bt}''.x_b + \sum_{e\in E}\sum_{t\in T} pol_{et}''.x_e,$$

$$\sum_{e\in E} x_e \geq 1,$$

$$\sum_{g\in G} x_g \geq 1,$$

$$\sum_{d\in D} x_d \geq 1,$$

$$\sum_{b\in B} x_b \geq 1,$$

$$\sum_{q_2}\sum_{n\in N} z^{ct}_{gbqs} = rr''^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lg}qs}\right)\forall g\in G, c\in C, t\in T, s\in S,$$

$$\sum_{g\in G} z^{ct}_{\mathrm{lg}qs} = r^c_{lqs}.\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls}\forall l\in L, d\in D, t\in T, q\in Q, s\in S,$$

$$\sum_{q1}\sum_{m\in M} z^{ct}_{gmqs} = rr^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lg}qs}\right)\forall g\in G, c\in C, t\in T, s\in S,$$

$$\sum_{m\in M}\left(z^{ct}_{mds} + w^{ct}_{mds}\right) = \sum_{l\in L} z^{ct}_{dls}\forall d\in D, c\in C, t\in T, s\in S,$$

$$\sum_{q2}\sum_{e\in E} z^{ct}_{geqs} = rr'^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lg}qs}\right)\forall c\in C, t\in T, g\in G, s\in S,$$

$$\sum_{q_2}\sum_{g\in G} z^{ct}_{gbqs} = \sum_q\sum_{m\in M} z^{ct}_{bmqs}\forall b\in B, c\in C, t\in T, s\in S,$$

$$\sum_{q_1}\sum_{m\in M} z^{ct}_{gmqs} + \sum_{q_2}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{q_3}\sum_{e\in E} z^{ct}_{geqs}, = \sum_{q}\sum_{l\in L} z^{ct}_{\text{lg}qs},$$

$$\sum_{n\in N} z^{ct}_{nms} + \sum_{q_1}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q\in Q}\sum_{b\in B} z^{ct}_{bmqs},$$

$$= \sum_{d\in D} z^{ct}_{mds} \forall m \in M, c \in C, t \in T, s \in S,$$

$$\sum_{d\in D} z^{ct}_{dls} = d^{ct}_{ls} \forall l \in L, c \in C, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{m\in M} z^{ct}_{nms} \le li_n \forall n \in N, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{c\in C}\sum_{d\in D} z^{ct}_{mds} \le li_m \forall m \in M, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls} \le li_d x_d \forall d \in D, t \in T, s \in S,$$

$$\sum_{q_3}\sum_{c\in C}\sum_{g\in G} z^{ct}_{geqs} \le li_e x_e \forall e \in E, t \in T, s \in S,$$

$$\sum_{c\in C}\left(\sum_{q_1}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q}\sum_{b\in B} z^{ct}_{bmqs}\right) \le li'_m \forall m \in M, t \in T, s \in S,$$

$$\sum_{qs_1}\sum_{c\in C}\sum_{g\in G} z^{ct}_{gbqs} \le li_b x_b \forall b \in B, t \in T, s \in S,$$

$$\sum_{q_1}\sum_{c\in C}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q_3}\sum_{c\in C}\sum_{e\in E} z^{ct}_{geqs} + \sum_{q_2}\sum_{c\in C}\sum_{b\in B} z^{ct}_{gbqs} \le li_g x_g$$

$$x_d, x_g, x_p, x_e \in \{1, 0\} \forall d \in D, g \in G, b \in B, e \in E,$$

$$z^{ct}_{gmqs}, z^{ct}_{mds}, z^{ct}_{dls}, z^{ct}_{bmqs}, z^{ct}_{mds}, z^{ct}_{\text{lg}qs}, z^{ct}_{geqs}, z^{ct}_{nms}, z^{ct}_{gbqs} \ge 0. \tag{1}$$

The objective function (1) is to minimize the costs of establishment, product flow, transportation, cost of returning products, and costs of burial, collection, and manufacturing. The objective functions (3-4), which consist of two parts, include minimizing the adverse effects of carbon dioxide due to the establishment of centers and transportation. The objective function (5) is to minimize risks. In fact, the model will try to establish facilities in areas with a lower risk of pollution and smaller population.

Constraint (6) indicates that at least one burial center should be established. Constraint (7) indicates that at least one collection center should be established. Constraint (8) indicates that at least one distribution center should be established. Constraint (9) implies that at least one recycling center should be established. Constraint (10) shows the balance between collection and recycling centers. Constraint (11) indicates that all returned products must be received from customers. Constraint (12) shows the balance between collection and manufacturing centers. Constraint (13) indicates the amount of products sent to the customer. Constraint (14) shows the balance between collection and burial centers. Constraint (15) shows the balance of the recycling node. Constraint (16) indicates the amount of products sent from the customer to the collection center. Constraint (17) indicates the quantity of products sent from the manufacturer to the distributor. Constraint (18) indicates that demand must be fully met. Constraint (19) indicates the capacity of suppliers. Constraint (20) indicates the capacity of manufacturers. Constraint (21) indicates the capacity of distributors. Constraint (22) ensures that a burial center can be used if it is established. Constraint (23) indicates the capacity of the manufacturing center to recover products. Constraint (24) ensures that a recycling center can be used if it is established. Constraint (25) shows the capacity of collection centers. A collection center can be used if it is established. Constraints (26-27) indicate the type of decision variables.

4. Results

The NSGA-II algorithm is one of the most powerful multiobjective problem-solving methods. This method was first introduced by Deb et al. [27]. This approach has steps such as

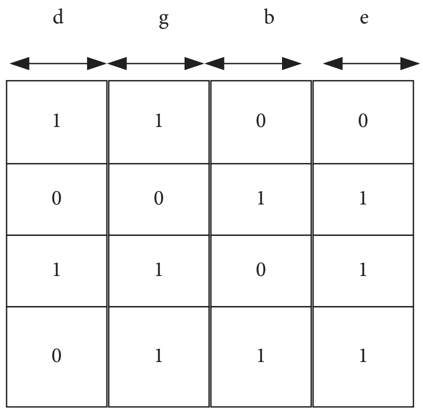

Figure 2: Chromosome structure.

chromosome display, cross over, mutation, and parameterization. Successful applications of this method have been reported many times. Among the advantages of the NSGA-II approach over other meta-heuristic approaches are low solution time, high convergence speed, and compatibility with a variety of mathematical models [28, 29]. The following are the reasons for the superiority of the NSGA-II algorithm over other algorithms:

(1) The NSGA-II algorithm uses only the values of the objective function to perform the optimization process and does not require additional information such as the function derivative; (2) Due to the simplicity of the search process of the NGSA-II, it works very quickly and efficiently.

4.1. Chromosome Display. The proposed chromosome is multidimensional. For example, chromosome 1 consists of 4 parts. This chromosome describes the following 4 variables (Figure 2):

x_d If center d is established, 1, and otherwise, 0.

x_g If center g is established, 1, and otherwise, 0.

x_b If center b is established, 1, and otherwise, 0.

x_e If center e is established, 1, and otherwise, 0.

The main operators of this method are mutation and cross over, which are defined in this research as follows. Figure 3 shows the cross-over operator. A two-point cross over has been used in this research. The mechanism of this operator is such that two points are randomly selected, and the strings of each chromosome are replaced.

Figure 4 shows the mutation operator. So, a row is selected as desired and the selected row will be reversed.

4.2. Parameters of NSGA-II Algorithm. The parameter setting was carried out in this study using the Taguchi approach, which is reported as follows (Table 2).

4.3. Metrics for Comparing the Performance of Multiobjective Algorithms. There are several metrics for evaluating the performance of the proposed algorithm, which are discussed in the following. The algorithms are compared with each other using the metrics of time, mean ideal point distance, maximum spread, spacing, and the number of Pareto solutions; the method of calculating these metrics is given below as follows:

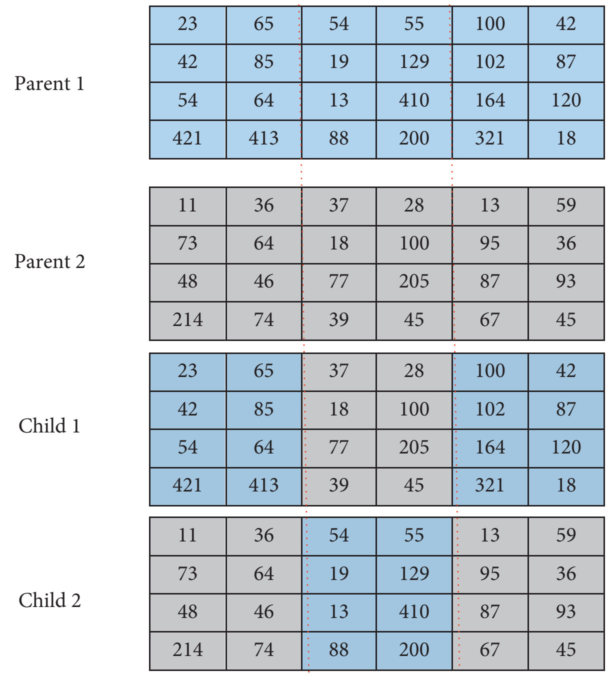

Figure 3: Two-point cross over.

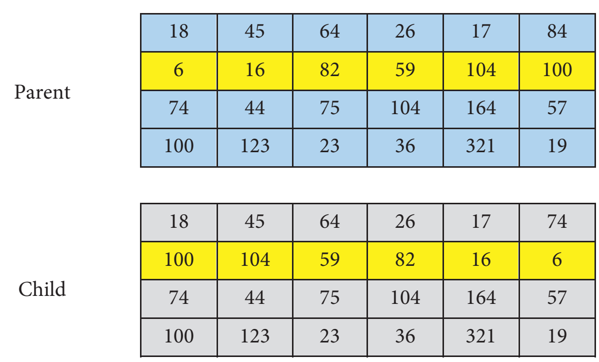

Figure 4: Mutation operator.

Table 2: Parameter setting.

Parameter	Explanation	Value
NPop	The number of population	100
MaxIt	The number of repetitions	100
Pc	Intersection rate	0.7
Pm	Mutation rate	0.3

(i) Mean ideal point distance (MID): this metric calculates the mean ideal point distance for each member of the Pareto front (the ideal point is the origin of the coordinates for the problem), and the less its value, it is better. In the following relation, n is the number of Pareto points and $f_{1,\text{total}}^{\max}$ and $f_{1,\text{total}}^{\min}$, respectively, are the highest and lowest values of the objective function among all the objective functions of the algorithm:

Table 3: Parameters of the numerical example.

Value	Parameter	Value	Parameter
$\mathbf{U} \sim [100, 200]$	$d^c_{gmqs}, d^c_{nms}, d^c_{mds}, d^c_{lgs}$	$U \sim [2000, 3000$	li_n, li'_m, li_e
$\mathbf{U} \sim [300, 400]$	$d^c_{gbqs}, d^c_{geqs}, d^c_{bmqs}, d^c_{dls}$	$U \sim [3000, 4000]$	$li_m, li_g, li_b, li_{\mathrm{d}}$
$\mathbf{U} \sim [0.4, 0.6]$	pr_s	$U \sim [1, 2]$	cb''_e, cb''_g, cb'_b
$\mathbf{U} \sim [0.5, .07]$	$r^{ct}_{l,q,s}, rr'^{ct}, rr^{ct}, rr''^{ct}$	$U \sim [2, 3]$	cb_{d}, cpk
$\mathbf{U} \sim [20, 30]$	$\mathrm{pol}_{\mathrm{d}t}, \mathrm{pol}'_{gt}, \mathrm{pol}''_{bt}, \mathrm{pol}''_{et}$	$U \sim [1500, 2500]$	$h''_d, h''_p, h'_g, h_{\mathrm{d}}$
$\mathbf{U} \sim [1, 5]$	pg^s	$U \sim [50, 100]$	vl_{cs}
$\mathbf{U} \sim [5, 10]$	d^{ct}_{ls}	$U \sim [6000, 8000]$	$fo_{cs}, f'o_{cs}$,

Table 4: Scale of numerical examples.

Scale	Numerical samples	Burial centers	Collection centers	Manufacturing centers	Recycling points	Customers	Distribution	Suppliers
Small scale	Sample 1	1	2	1	1	1	1	1
	Sample 2	2	2	2	2	1	2	2
	Sample 3	2	2	3	2	2	2	3
	Sample 4	2	3	3	2	1	3	3
Medium scale	Sample 5	3	3	3	3	2	3	3
	Sample 6	3	3	4	3	2	3	4
	Sample 7	4	4	4	3	2	3	4
	Sample 8	4	4	4	4	2	4	4

$$\mathrm{MID} = \frac{\sum_{i=1}^{n} \sqrt{\left(f_{1i} - f_1^{\mathrm{best}} / f_{1,\mathrm{total}}^{\max} - f_{1,\mathrm{total}}^{\min}\right)^2 + \left(f_{2i} - f_2^{\mathrm{best}} / f_{2,\mathrm{toal}}^{\max} - f_{2,\mathrm{total}}^{\min}\right)^2}}{n}. \tag{2}$$

In the above relation, the coordinates of the ideal point are equal to $(f_1^{\mathrm{best}}, f_2^{\mathrm{best}})$.

(ii) Spacing metric: this metric evaluates the uniformity of distribution of solutions on the Pareto front and is calculated as follows:

$$\mathrm{SM} = \frac{\sqrt{\sum_{i=1}^{n} \left(d_i - \overline{d}\right)^2 / n}}{\overline{\mathrm{d}}}. \tag{3}$$

In the above relation, n is the number of Pareto solutions and d_i is the Euclidean distance between the Pareto solutions on two sides of the solution space. Also, $\overline{\mathrm{d}}$ is the mean distance of d_i. The low value of this metric indicates a more uniform distribution of the solution among the identified Pareto solutions.

In this part, numerical examples are provided to prove the proper performance of the proposed mathematical model. Table 3 shows the values of the parameters used in the example. As can be seen, a uniform function is used for all parameters in the specified intervals. For example, the probability of scenarios occurring between 04 and 0.6 is considered. The considered values are based on a uniform distribution.

Table 4 shows the scale of numerical examples. As it is obvious, there are 8 numerical samples. Examples 1 to 4 are small scale, and examples 5 to 8 are medium scale. As the scale of the problem increases, so does the number of nodes in the problem. For example, in the first example, the number of burial centers, collection centers, manufacturing centers, recycling points, customers, distribution, and suppliers is equal to 1, and in sample 6, 3 burial centers, 3 collection centers, 4 manufacturers, 3 recycling points, 3 customers, 3 distributors, and 4 suppliers are considered.

Table 5 shows the results of solving the model in medium and small scales. The first four examples are related to the mean solutions of the model in small scale, and the next four examples are related to the mean solutions of the model in medium scale. In this table, the results of the exact solution are compared with the results of the NSGA-II method. Also, the solving time of each method and the percentage error values, which indicate the difference between the exact and meta-heuristic solutions, is given in the last row. The results of the solution indicate that as the scale of the problem increases, the solving time of both methods increases. However, the speed of increasing the solving time of the epsilon-constraint method is much higher than that of the NSGA-II. The average solution time with the exact method is 6.1 seconds and with the meta-heuristic method is 23.6. Therefore, according to the results of Table 5, the NSGA-II algorithm can be trusted to solve large-scale problems and its good performance can be predicted.

Figure 5 shows the solving times of numerical examples. As can be seen, the solving time increases by increasing the scale of numerical examples. The solving time of the first example is 18.51 seconds for the exact solution and 21.3 seconds for the meta-heuristic solution. Also, by increasing the scale of the problem, the solving time of the exact approach suddenly increases from the fourth example. This increase happens exponentially. This increase continues until the solving time of the exact approach for the eighth example reaches 957.45 seconds. Therefore, it can be said

Table 5: Comparative results of solution for small and medium scales.

Row	Epsilon constraint				Nondominant sorting				Percentage error		
	f_1	f_2	f_3	Time (s)	f_1	f_2	f_3	Time (s)	f_1	f_2	f_3
1	509	289.4	3.46	1	509	289.4	3.48	1	0.00	0.00	0.57
2	541	300.2	4.74	37	542	300.2	4.77	5	0.001	0.0	0.62
3	649	302.1	5.36	49	650	303.3	5.37	6	0.001	0.003	0.18
4	691	320.3	6.01	99	693	321.9	6.03	14	0.008	0.005	0.33
5	1454	629	6.65	1021	1457	631.6	6.69	27	0.002	0.004	0.59
6	1568	737.5	7.2	1413	1572	740.4	7.25	34	0.002	0.003	0.68
7	1600	804.6	7.98	2934	1604	806.3	7.99	39	0.002	0.003	0.12
8	1909	983.3	8.1	7371	1911	987.6	8.19	63	0.001	0.003	0.09

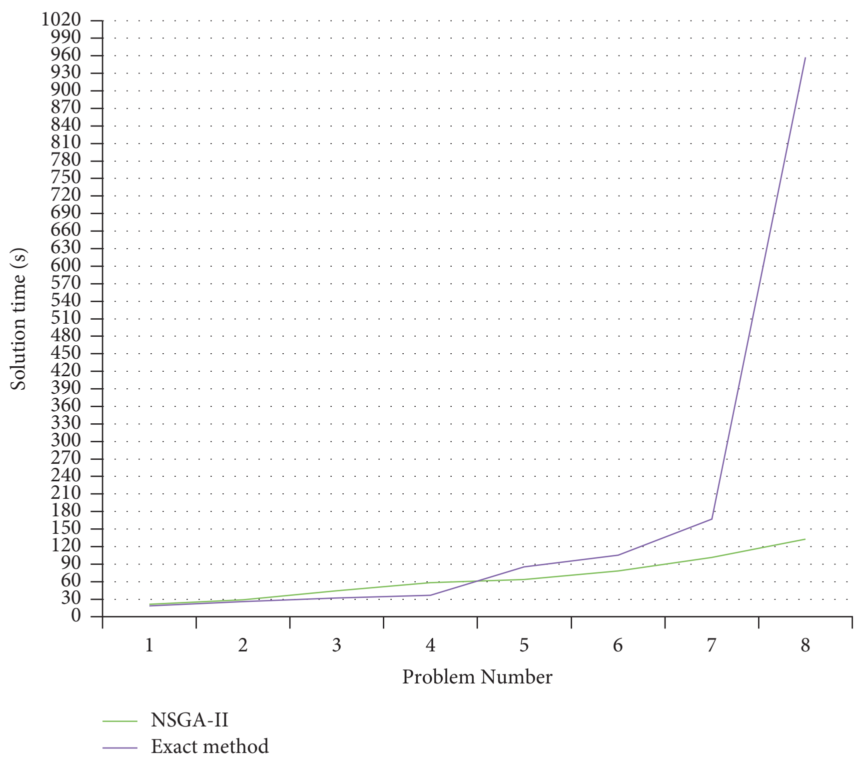

Figure 5: Solving time of numerical examples.

that according to the solving time, the problem is the NP-Hard, and according to the efficiency of the proposed meta-heuristic approach, this approach can be used for the case study.

4.4. Case Study. In this study, waste paper is sent to paper companies from all around Iran with a pattern of 70% from Karaj and Tehran. The price of each kilo of waste paper is about 6000 tomans, and the transportation cost for each kilo is about 100 to 350 tomans, depending on the near or far places that send the paper. Paper companies are in Tehran, Mashhad, Zanjan, Gilan, Mazandaran, Tabriz, Khuzestan, and Markazi. Centers for burying unusable waste are located in the area of paper companies in the centers of the provinces or surrounding cities. The cost of burial and delivery for burial centers is about 400 tomans per kilo of unusable waste, and this price exists for all burial centers, 300 tomans for burial, and 400 tomans for transportation. The products of cardboard box manufacturing companies in all of Iran are sent to the whole country and manufacturers of industrial equipment, etc. Basically, the delivery pattern is as follows: Tehran and Karaj 60%, exports to Iraq 5%, Tabriz 5%, Mazandaran 5%, Mashhad 5%, Zanjan 5%, Qom 5%, Qazvin 5%, Semnan 4%, Kerman 6%, Shiraz 5%, Khuzestan 5%, and other provinces 4%. It should be noted that scenario 1 is the

Table 6: Capacity parameter.

Centers	Capacity
Center 1	1000
Center 2	1500
Center 3	2000
Center 4	1000
Center 5	1000

Table 7: Pareto points obtained from solving the model.

No.	f_1	f_2	f_3	Time (s)
1	58290.1	3152.6	14.32	15
2	58413	3155	14.45	12
3	58332.1	3162.5	15.97	17
4	57911	3161.9	16.40	14
5	58202.2	3158.1	16.66	15
6	58320.6	3163.1	17.20	18
7	58373.3	3164.7	17.64	16
8	58374.2	3163.3	18.41	17
9	58426.4	3160.9	19.08	13
10	58576.5	3165.8	19.95	19

Table 8: Variable values of location of distribution, collection, recycling, and burial centers.

No.	Burial center	Recycling center	Collection center	Distribution center
1	0	1	1	1
2	1	0	0	1
3	0	1	1	0
4	1	0	0	1
5	1	0	1	1

Table 9: The amount of product flow from supply centers to manufacturing centers.

Scenario/period supply and manufacturing center	Scenario 2—period 2	Scenario 2—period 1	Scenario 1—period 2	Scenario 1—period 1
Supply 1 center to manufacturing 1 center	111	166	136	284
Supply 1 center to manufacturing 4 center	697	284	876	598
Supply 2 center to manufacturing 3 center	514	439	678	499
Supply 2 center to manufacturing 2 center	770	398	1059	548
Supply 3 center to manufacturing 5 center	423	240	647	267
Supply 3 center to manufacturing 4 center	914	411	1987	557
Supply 4 center to manufacturing 1 center	554	416	641	564
Supply 4 center to manufacturing 4 center	513	297	687	314
Supply 5 center to manufacturing 3 center	400	755	451	809
Supply 5 center to manufacturing 4 center	409	510	497	678

market boom, and scenario 2 is the market recession. Table 6 shows the capacity of burial centers.

4.5. Discussion. Table 7 shows the results of the case study. As can be seen, after solving the mathematical model, the Pareto points for a point are as follows. Due to the greater importance of the first objective function compared to the second objective function, a point is selected that has the best value of the first objective function. As it is known, with increasing the dimensions of the problem, the solution time also increases. Also, the average of the first objective function is 58321.94, the average of the second objective function is 3160.79, and the average of the third objective function is 17. Also, the mean solving time of the case study is 15.6 seconds.

Table 8 shows the location of potential centers. As it is shown, recycling center 1, collection center 1, and distribution center 1 will be established. Burial center 2 and distribution center 2 will also be established. Then, recycling center 3 and collection center 3 will be established. Burial and distribution centers 4 will also be established. Finally, burial center 5, collection center 5, and distribution center 5 will be established.

Table 9 shows the amount of product flow from supply centers to manufacturing centers in each scenario. As shown in the boom scenario, the flow of the product sent is greater than in the recession scenario. For example, the amount of products sent from supplier to manufacturer during periods 1 and 2 in the recession scenario is 111 and 166 units, respectively, and in the boom scenario, 136 and 284 units, respectively.

4.6. Sensitivity Analysis. Figure 6 shows the impact of changes in the capacity of established distribution centers on supply chain costs. As shown, the costs of the supply chain will decrease by increasing the capacity of distribution centers. The reason for this is that with the increase in capacity, the need to establish new centers is greatly reduced. According to this figure, reducing the capacity of distribution centers by up to 20% has led to increasing the objective function to 34,989 units. A 20 % increase in the capacity of distribution centers has reduced the objective

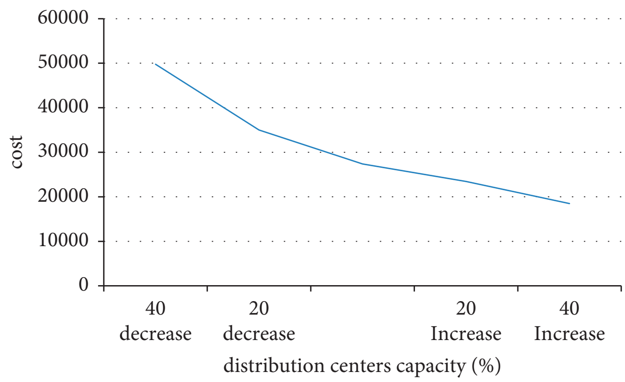

Figure 6: Sensitivity analysis of the objective function relative to the capacity of distribution centers.

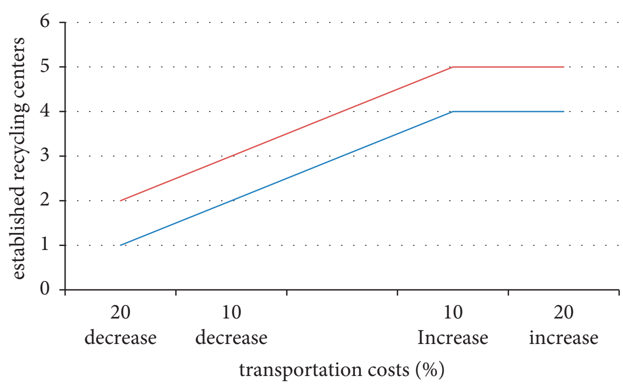

Figure 7: Sensitivity analysis of the number of established recycling centers relative to transportation costs.

function to 24,319 units. Also, a 40% increase in the capacity of distribution centers has reduced costs to 18,473 units.

Figure 7 shows the impact of changes in transportation costs on the establishment of recycling centers in different scenarios. A 20 % decrease in transportation costs has led to the establishment of one distribution center for the recession scenario and two distribution centers for the boom scenario. Also, a 10 % decrease in costs of transportation from manufacturer to distributor has led to the establishment of one distribution center for the recession scenario and two distribution centers for the boom scenario. With a 10% and 20% increase in transportation costs, the number of established centers in both scenarios remains constant. According to this figure, by increasing the transportation costs, the number of established distribution centers increases to a certain extent and finally remains constant. As it is shown, the reduction in transportation costs to the point of establishing four centers in the recession scenario and five centers in the boom scenario becomes saturated and is no longer able to minimize the number of established centers.

5. Managerial Insight and Practical Implications

In order to optimally reverse supply chain management, the use of new technologies for managers to achieve greater speed at a lower cost is noteworthy. Technology can help assess the status of returned goods at the lowest possible cost. Assessing the status of returned goods may lead to long delays and low reverse supply chain speeds. It is better for managers to design a reverse supply chain according to the needs of the organization, the type of products, and the product life cycle. The life cycle of goods and their products must first be determined. If the goods have a long life cycle, the speed of work can be sacrificed to reduce costs. In other words, the reverse supply chain system can be designed and managed in a way that is slower and costs are reduced instead. The results of this research can be useful for all types of wood, paper, and cellulosic factories.

6. Conclusions

It should always be noted that the returned goods should be viewed as a valuable asset. In many companies, such as Germany's Bosch, returned goods are viewed as valuable assets rather than a waste stream of unusable waste. Given that many components have a limited life cycle and will soon lose their value if not used in a timely manner, the company's executives place great emphasis on extracting the maximum possible benefits from the returned goods.

This study investigates the supply chain of cellulosic products in Iran. In the first step of this research, semi-structured interviews were conducted with professors, managers, and experts of different levels of the cellulose manufacturing companies to fully understand the concepts and identify the dimensions and components of the research problem, and then, according to the research literature and examining the conditions of the company, important criteria, and indicators in reducing total supply chain costs were identified. In the next step, mathematical modeling was conducted with the objective of minimizing economic and environmental costs and satisfying the risk of social responsibility, and then, the exact solution of the model was carried out using information about the factory and by GAMS software for small and medium scale and by the NSGA-II method for large scale. In the next step, the sensitivity analysis was performed on the effective parameters to identify the minimum amount of recycled wood required to make recycling a cost-effective option. The results of this study are as follows:

(1) The results show that by increasing the transportation costs, the number of established distribution centers increases to a certain number and then remains constant.

(2) Decrease in the transportation costs to the point of establishing four centers in the recession scenario and five centers in the boom scenario becomes saturated and is no longer able to minimize the number of established centers.

(3) Also, by increasing the capacity of distribution centers, supply chain costs are reduced. The reason is that by increasing the capacity, the need to establish new centers is greatly reduced.

As there was no official database for some parts of cost elements, the driver's estimations were asked to help. The questions about the transportation costs for each route have been categorized, and the estimated costs have been entered into the mathematical model [30–33].

The suggestions for future studies are as follows:

(1) Considering other solution approaches such as heuristic approaches, and meta-heuristic approaches such as the gray wolf and particle swarm algorithms.

(2) Considering other uncertainty approaches such as fuzzy

(3) Considering the resilience and risk of disruption in the proposed supply chain

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Solving the Problem of Time, Cost, and Quality Trade-Off in Project Scheduling under Fuzzy Conditions Using Meta-Heuristic Algorithms

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Balancing the project's time, cost, and quality involves deciding on different implementation methods for each project activity. Time and cost are minimized simultaneously, and the quality of the final product or service is maximized. Indeed, the use of search methods to determine the optimal execution methods of each activity requires the evaluation and review of various performance criteria such as time, cost, and especially the final quality of each activity. These performance measures, especially the quality of the different implementation methods, are reported and recorded in inaccurate, ambiguous, and vague numbers or concepts. In this research, new methods have been proposed to evaluate and investigate the trade-off of time, cost, and quality of the project in conditions of uncertainty. This means that by fuzzy number theory, the specifications and conditions of a project are included in the problem of balancing time, cost, and quality. In fact, time, cost, and quality are considered triangular and trapezoidal fuzzy numbers. Also, the fuzzy multiattribute utility function approach (in which the concept of fuzzy computational operators is included) has been used to evaluate different combinations of execution methods of project activities. Since different quality combinations can be obtained with different combinations of parameters involved in the implementation of an algorithm, the Taguchi experimental design method has been used to adjust the parameters of the proposed algorithm. To solve the proposed model, particle mass optimization algorithms and artificial bee colonies have also been studied.

1. Introduction

A project is a set of temporary efforts to achieve a specific goal (product creation or service delivery). The term "temporary" means that projects start and end at specific times, and the term "specific" also means that the service or product in question is well-defined and distinct from the results of other projects. One of the essential activities that must be done in the management and control of a project is deciding how and when to implement each activity. Project scheduling determines a time sequence in the form of a schedule to perform interrelated activities that form a network called a project. Dependence of activities is an order that must be observed in their precedence and latency due to technical limitations in project implementation. Indeed, following a logical sequence of actions or technical constraints in scheduling a project's activities alone cannot meet the expectations and demands of the various groups involved, such as project managers and stakeholders.

In general, in trying to schedule project activities, project managers always try to control the available resources along with time, cost, and quality constraints. Since the project is fundamentally unique, there is no logical standard for project planning. As a result, decisions are made in a triangle of time, cost, and quality (as in Figure 1).

It can be said that more effective and efficient implementation methods (using different resources and technologies) in project activities can lead to other times, costs, and qualities. In general, the use of cheap resources and technologies will generally lead to an increase in project

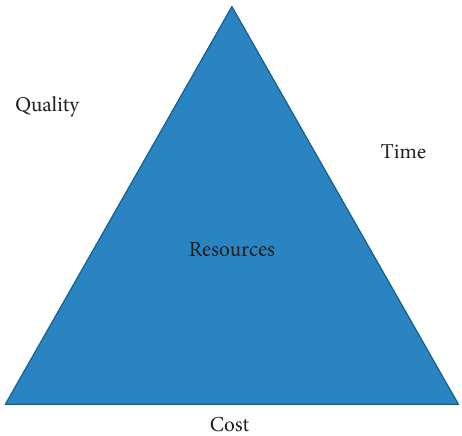

Figure 1: Project management triangle.

execution time. For example, hiring more skilled artisans or more workers in a construction project can reduce the time it takes to complete project activities, but project costs will undoubtedly increase. To determine the optimal combination of different methods of implementing the actions of a project, various approaches have been developed to solve the problem of time and cost trade-off. These approaches include innovative methods [1, 2], mathematical methods [3–6], and evolutionary methods [7–10]. However, it should be noted that reducing project time and costs may reduce the overall quality of the final product or service. For example, reducing the cost and time of projects such as the construction of subways, bridges, and roads can reduce the overall quality of the project, which, in the long run, will significantly increase the costs of the operation period, such as depreciation and maintenance costs.

All these reasons have caused the issue of trade-off of time, cost, and quality of the project in the last two decades to attract the attention of many researchers and extensive research in this field. Babu and Suresh [11] have proposed three linear programming models for this problem, considering a logical relationship between time, cost, and quality. Using the Babu and Suresh [11] approach in a cement plant construction project in Thailand, Khang and Myint [12] examine this approach's practical application, assumptions, and fundamental issues. Other researchers [13] have applied the concept of time, cost, and quality trade-off using the idea of multiobjective optimization. One of the most critical challenges in applying these approaches is using historical reports or the knowledge of elites, contractors, and engineers to determine resource utilization plans or procedures. Different programs for the exploitation of renewable or nonrenewable resources or other implementation methods will lead to various equipment, human resources, and materials allocation. This will undoubtedly affect project performance levels such as time, cost, and quality.

On the other hand, time, cost, and quality functions are generally not exact numbers and are sometimes difficult to express as actual numbers. In practice, project managers, engineers, or experts use uncertain, vague, or inaccurate terms to estimate and express these performance levels. For example, the quality of activity might be defined as "most likely equal to a, but certainly not less than b and not greater than C." However, most of the time, cost, and quality trade-off approaches use exact numbers to express different criteria and will be inefficient in analyzing vague, perceptual, and uncertain relationships between these performance criteria.

This paper examines the issue of cost-time trade-off by considering the project quality factor as one of the pillars of the project. New methods have been proposed in recent years regarding the issue of cost-time balance. In project scheduling calculations, the earliest time to complete the last activity is the project delivery date. Project completion time is generally reduced by revising network logic or shortening activities at a higher cost. As the duration of activities decreases, the quality of each movement, i.e., the proximity of the project deliverables to the expectations of the employer or the customer, decreases. In discussing the balance between the three functions of cost, time, and quality of the project, cost sensitivity analysis is performed to changes in the duration of the activity, which aims to obtain the best combination of time reduction of activities. In such a way, the total project costs are minimized, and the quality of the whole project is maximized.

As mentioned, uncertainty, ambiguity, and the perceptual and inferential performance of time, cost, and quality for all activities in a project are inevitable. In this research, considering the uncertainty for the mentioned functions and the trapezoidal or triangular fuzzy numbers to express these functions, the problem of time, cost, and the quality balance becomes a fuzzy problem of time, cost, and quality balance. Therefore, using fuzzy logic and multiattribute utility and fuzzy critical path. Using this algorithm, a better execution method with higher desirability is selected, and using the superinnovative particle swarm optimization algorithm and artificial bee colony can create space. The problem is searched, and according to the search and stop conditions, the best answer found is determined as the desired answer to the problem.

In the following, in Section 2, the research background is examined. Section 3 describes the research method. In Section 4, the results are numbered and analyzed, and finally in Section 5, conclusions are made.

2. Literature Review

The early techniques used to schedule large projects date back to the late 1950s. The famous critical path method in 1961 and the modern project management (MPM) method in 1962 were designed for projects whose activities have a definite time. The biggest problem with these methods is that they take into account only the limitations of the prerequisite. Early models of problems with resource constraints were introduced in the early 1960s. The first systematic method developed to optimize the project schedule is the critical path method. This method, also called critical path analysis, results from a collaboration between DuPont and Remington Rand in the year 7 AD. In this method, the duration of the activities is estimated as a numerical value, and it is assumed that the changes in this period are minimal and negligible. This condition is evident in projects where similar examples have been implemented in the past or experiences from the duration of the activities are available.

Coinciding with the introduction of the critical path approach to project scheduling, the US Navy, in collaboration with Bose's management consultants Allen Hamilton and Lockheed Aircraft, introduced project evaluation and review techniques in the Polaris submarine project scheduling. The success of this method in scheduling the Polaris project led to the expansion of the use of this method in later years. The main application of the program evaluation and review method is in projects where there is uncertainty in the duration of activities, and a fixed numerical value cannot be used to estimate the time of activities.

2.1. Cost-Time Trade-Off Issue. The critical path method is a mathematical algorithm used to schedule a set of activities in various projects such as construction, engineering, facility maintenance, and software development. This method is related to the balance between completion time and project costs [14], and its application in definite conditions is more appropriate than possible conditions. The critical path method is used to determine the time-cost balance for activities that meet the completed time at the lowest cost and is also useful when there are similar experiences from previous projects [15].

Time-cost balance issues have focused on shortening the entire project time by reducing the time required to complete activities since the late 1950s. Researchers in linear scheduling models [1, 14, 16–19] and nonlinear scheduling models [20–22] are based on the assumption that time and cost balances for activities are linear. The relationship between the duration of activity and the cost of a straight line is expressed on a graph [23]. The cost of completing the activity varies linearly between normal time and reduced time. There is a continuous, linear relationship between cost and time for each activity in the classical case. One development considers this a situation where resources are limited, and the relationship between cost and time is discrete. These studies include the work of Demeulemeester et al. [24]. In this case, a certain amount of time is taken to perform the activity for a certain amount of resources. Erenguc et al. [25] considered developing this cost-time equilibrium model, in which activities can be reduced by allocating more resources to optimize the current net value of the project. Hazir et al. [26] presented the problem of discrete cost-time balance for the project scheduling problem in multimode concerning specific relationships. Ballestin and Blanco [27] also theoretically and practically optimized multiobjective functions in RCTSP. Lotfi et al. [28] have researched renewable energy. The most important innovations in their study included the use of robust two-level programming techniques and game theory (Stackelberg Competition) for locating renewable energy sites. The results show that the combination of uncertainties can increase energy production and supplier profits. In addition, the objective functions of the proposed model are compared with those under uncertain conditions. Sensitivity analysis of the main parameters is performed to validate the proposed model. As uncertainty increases, the energy produced decreases and the supplier's profit increases. Supplier profits gradually decrease as the discount rate increases. In addition, as the scale of the problems increases, the energy produced and the profit of the supplier increase. Babu and Suresh [29] conducted a study to balance the three factors at the same time. In their work, they made a Crashing Hypothesis and assumed that as the time of activity decreases, cost increases linearly and quality declines linearly. They considered three linear target functions in which the result analysis led to decision-making in balancing the mentioned factors. At the end of their paper, they proposed that neither the total quality of the project (whether weighted mean or arithmetic mean) nor the quality calculation as the product of the activities affects their work result procedure. Zheng et al. [30] made efforts to introduce optimal solutions based on genetic algorithm (GA). However, in all these studies, uncertainties were not considered due to complications, and the studies were conducted in a deterministic space. But in real-world projects, factors such as cost and time of the projects are always affected by many changes due to the uncertainties. Therefore, to solve this problem, Feng et al. [10], Azaron et al. [31], Abbasnia et al. [32], and Zhang and Li [33] studied the bi-objective balance of time and cost in a real-world uncertain space. Khang and Myint [34] implemented this model in a real-world project of construction of a cement factory in Thailand. The successful experience of meta-heuristic optimization algorithms in solving the two-factor problem of time-cost balance made the researchers focus on solving the three-factor problem of time-cost-quality optimization. Abolghasemian et al. [35] considered the sustainability pillars in scheduling projects and uncertainties in modeling them. To model the study problem, robust nonlinear programming (NLP) involving the objectives of cost, quality, energy, and pollution level is applied with resource constrained. Abolghasemian et al. [35] considered delay scheduling based on discrete-event simulation for construction projects. For this purpose, rework parameter and the variables of frequency, duration, and time of callback have been considered. Also, the effects of these parameters on tangible performance criteria have been investigated. The combined approach of discrete-event simulation and computational modeling is applied and then the results are compared. Measurements show that the systems fragmented by repeated and short repetitions while referring to early are in optimal performance.

2.2. Research Gap. The complexity of the proposed algorithms is significant for solving these problems. It can be very annoying for important issues, even with the advances in computer programming and the hardware used to run these programs today. Researchers are more likely to use innovative and meta-innovative methods to solve this problem to escape this complexity. The development of precision methods is also crucial because the only valid scale by which innovative and meta-innovative methods can be evaluated are these precise methods. In Table 1, previous studies are categorized with research methodologies.

3. General Definition of the Proposed Problem

As mentioned, a project involves a set of specific activities. Here, the activities of a project are numbered $j = 1, 2, \ldots, n$. The time or duration of an activity j is displayed with D_j.

As soon as another activity starts, it is impossible to stop the action, and there is no interruption in implementing project works. Due to technological and executive needs, there are prioritized relationships between project activities. These relationships are represented by a set of prerequisites for a P_j activity. These sets mean that the activity cannot start before the prerequisite activity $i \in P_j$. The basic premise is that these networks are nonrotational. In the display of each project, two additional activities $j = 0$ and $j = n + 1$ are defined, which indicate the beginning and completion of the whole project. These two activities are virtual, have zero execution time, and do not use any resources.

The project's time, cost, and quality are determined by the time, cost, and quality of the constituent activities. On the other hand, these criteria for each of the activities in the project network depend on its implementation method. In fact, the implementation method includes the program of utilizing various resources (equipment, human resources, materials, etc.) and specific implementation techniques. For example, consider the concreting activity in a construction project. This activity can be done in three ways.

(1) Making concrete on-site by a mixer and a skilled worker

(2) Use ready-mixed concrete and transport it to the site using appropriate equipment

(3) Using prefabricated concrete blocks and transporting them to the site.

The project completion time can be calculated by summing the critical route activity times. The project's cost will be obtained from the sum of the costs of each project activity. A weighting approach will also be used to determine the overall quality of the project. The weight of each activity indicates its importance and impact on the overall quality of the project. Usually, using more effective execution methods reduces the time to perform an action, but you have to pay more for using more efficient resources and technologies. This means paying more for the quality of an action. Finding a solution to the problem of balancing time, cost, and quality involves determining the optimal combination of execution methods for all the activities that make up the project so that an optimal variety of time, cost, and quality is created for the project.

Performance criteria of time, cost, and quality related to different implementation methods of each activity are collected and calculated by project managers or engineers based on past or current experiences or based on the opinion of experts. Of course, it is not possible to express these parameters, especially the quality of an activity, in precise and specific values. In addition, due to environmental and temporal conditions, and especially the mentality of managers and engineers in estimating various parameters, project activities' evaluation or performance criteria are expressed in an uncertain, vague, and inaccurate manner. On the other hand, fitting and estimating the relationship between the implementation method of activity and the performance criteria related to that activity can be very weak due to the uniqueness of the project or its activities and other factors such as environmental conditions, equipment specifications, staff efficiency, material supply conditions, and coordination problems between stakeholders and retailers. Therefore, the existence of uncertainty and ambiguity in evaluating and expressing the performance of each project activity as well as the project as a whole is obvious and unavoidable.

In time balance, cost, and project quality, very strong and efficient models over time have been presented. However, as a development on the current models, as well as to investigate the issue of time balance cost and quality due to the ambiguity and uncertainty in determining and expressing the performance criteria of each project activity (the issue of time balance, cost, and fuzzy quality), the multiattribute utility technique will be studied. In this technique, time, cost, and quality of each project activity and time, cost, and overall quality of the project are considered as fuzzy numbers.

3.1. Research Assumptions. In the previous section, along with a description of the proposed problem, the various assumptions and topics in the problem are examined. Still, in general, the assumptions considered in this dissertation can be presented as follows:

(i) There is no interruption in the implementation of various project activities.

(ii) Due to technological and executive needs, project activities have prioritized relationships.

(iii) The activities that make up the project or its network are nonrotating.

(iv) Each project activity can be implemented in a small number of different implementation methods.

(v) Activities are definite, but each activity's duration, cost, and quality are uncertain, vague, and inaccurate.

(vi) Using effective and efficient execution methods reduces the execution time of each activity.

(vii) The use of effective and efficient execution methods increases the quality of execution of each activity.

(viii) Applying effective and efficient implementation methods increases the costs of each activity.

(ix) Data on each activity's time, cost, and quality are trapezoidal or triangular fuzzy numbers.

(x) To calculate the desirability of each execution method in the problem of balance of time, cost,

Table 1: Categorized previous study.

Author(s)	Reference number	Method					
		GT[1]	Robust	LP[2]	NLP[3]	GA[4]	Simulation
Lotfi et al.	43	*	*				
Babu and Suresh	44			*			
Zhang et al.	45					*	
Lotfi et al.	51				*		
Abolghasemian et al.	52						*

Note. [1]Game theory (GT). [2]Linear programming (LP). [3]Nonlinear programming (NLP). [4]Genetic algorithm (GA).

and fuzzy quality, the multiattribute utility technique is used. Then, the best answer (best execution method) is found using a meta-innovative algorithm.

(xi) The total project time is calculated based on the time of activities located in the critical path, and the fuzzy critical path method is used to find the end time of the project. The project's total cost is obtained from the sum of the cost of each independent activity in the project, and the total quality of the project is obtained through a weighting approach to each activity and the sum of the weighted quality of each activity for all projects activities.

3.2. An Overview of the Issues of Trade-Off of Cost, Time, and Quality of the Project. When a project is completed, the time-cost trade-off issue is an issue for the project manager, and quality or performance becomes a key issue [36]. In balancing the cost and time of the project, in a situation where the quality decreases after reducing the time of activities, the reduction of project activities is not desirable. As a result, it is better to increase the project completion time [20, 37]. In such cases, which may occur during the implementation of the project, preventive measures are taken to prevent rework or changes. Contractor time, cost, and project management requirements are important elements in determining the success of information systems and technology projects [38]. The quality of the method obtained helps project managers determine changes in project activities' quality. It helps them achieve the correct initial activities with the actual quality compared to the planned quality [39].

Project quality results from the accumulated contributions of all activities implemented throughout the project life cycle. If the project's output meets the expectations of the project contractor, the project is considered successful [40]. The project contractor prioritizes the availability of results in the long run because the project must be profitable. Completing the project on time and within budget is not enough because the work must also be of acceptable quality.

Previous research has shown that project quality is more important than other factors such as time and cost and is also satisfactory for defining a successful project. The contractor's consent is essential for success because the project output is passed on to the contractor [41].

Scheduled projects are usually supplemented by rework or modification in time-cost balance issues. The project is a set of one-time activities limited by time, cost, and quality factors, and its success depends on establishing a good balance between the three factors mentioned [42]. If any of the factors are overemphasized, the weight of the project falls on the other two factors. Therefore, the failure of project activities should be considered an essential factor in balancing issues.

3.3. Proposed Model. The proposed model in this dissertation is in the multiobjective project scheduling problem in multimode mode. Over the past decade, the issue of multimode project scheduling has become a standard issue in the subject literature, which can be summarized as follows. The multimode project scheduling problem considers an active project, each numbered $j = 1, 2, \ldots, n$. As soon as another activity starts, it is impossible to stop the activity, and there is no interruption in implementing project works. Due to technological and executive needs, there are prioritized relationships between project activities. These relationships are represented by the set of prerequisites for an activity P_j. These sets mean that the activity cannot start before the prerequisite activity $i \in P_j$. Introductory relationships with an activity on node network can be displayed. The basic premise is that these networks are nonrotational. Each of the activities in this network can be completed with different implementation methods (using other resources and technologies). These execution methods or different modes of activity execution are finite, and using each of them will lead to extra time, cost, and quality for each activity. In fact, in the execution of activity j, there are k_j types of execution methods, each of which is numbered with the numbers $k = 1, 2, \ldots, K$. The time, cost, and quality of performing the activity in executable mode are displayed with D_{jk}, C_{jk}, and Q_{jk}, respectively. In the display of each project, two additional activities $j = 0$ and $j = n + 1$ are defined, which indicate the beginning and completion of the whole project. These two activities are virtual, have zero execution time, and do not use any resources.

A timetable for assigning end times F_j to different activities is defined. The purpose of the proposed model is to perform all project activities only in one of the possible modes so that the prerequisite relationships are satisfied and create a balance between the three objective functions of cost, time, and quality of the project.

3.3.1. Proposed Model. This model lists all the constraints required for a multimode project scheduling problem. This model is the basis of most of the research that has been done in this field, which is described in detail in the second chapter, so it is fully described in this section. The parameters used in the model are as follows:

(i) Model Assumptions

The network of nodes AON as a graph $G = (V, E)$
Virtual activity 1 Initial activity and virtual activity n End activity of the network
Divide the project into smaller phases
Time is a continuous element

(ii) Indices

i, j: index of the number of activities $i, j = \{1, 2, \ldots, n\}$
m: the number of times to perform each activity $m = \{1,2, \ldots, n\}$

(iii) Symbolization

d_{jm}: time to perform j^{th} activity in m mode
D_j: the time to perform the w activity by considering the execution modes m^{th}
c_{jm}: the cost of doing j activity in m mode
C_j: the cost of performing the j^{th} activity by considering the executive modes m
q_{jm}: the quality of j activity in m mode
Q_j: the quality of performing the j activity by considering the execution modes m
w_j: the weighting factor of the effect of the quality of j activity on the quality of the whole project
P_j: a set of prerequisite activities for j
TH: schedule horizon

(iv) Variable

x_{jm}: if hm activity is performed in j^{th} mode, it is equal to one; otherwise, it is zero.
F_j: the time of completion of j activity

The first model:

$$\min Z_1 = F_n, \tag{1}$$

$$\min Z_2 = \sum_{j=1}^{n} C_j, \tag{2}$$

$$\max Z_3 = \sum_{j=1}^{n} w_j \cdot Q_j, \tag{3}$$

$$\sum_{m=1}^{m_j} x_{jm} = 1, \quad \forall j = 1, 2 \ldots, n, \tag{4}$$

$$D_j = \sum_{m=1}^{m_j} x_{jm} \cdot d_{jm}, \quad \forall j = 1, 2 \ldots, n, \tag{5}$$

$$F_j \geq F_k + D_j, \quad \forall j = 1, 2 \ldots, n, \forall k \in P_j, \tag{6}$$

$$C_j = \sum_{m=1}^{m_j} x_{jm} \cdot c_{jm}, \quad \forall j = 1, 2 \ldots, n, \tag{7}$$

$$Q_j = \sum_{m=1}^{m_j} x_{jm} \cdot q_{jm}, \quad \forall j = 1, 2 \ldots, n, \tag{8}$$

$$\begin{aligned} &x_{jm} \in \{0, 1\}, \quad \forall j = 1, 2 \ldots, n, m = 1, 2, \ldots, m_j, \\ &F_j \in R, \quad \forall j = 1, 2 \ldots, n. \end{aligned} \tag{9}$$

Constraint (4) ensures that j activity must be performed in only one of its modes. The next constraint (5) determines the time required for each project activity by considering the execution mode of each activity. One of the essential limitations of the specified project scheduling problem is the operational sequence of activities based on the prerequisite relationships of the activities. This limitation is given in equation (6). In this equation, the completion time of an activity is always greater than the completion time of its prerequisite activities plus the duration of that activity.

Limits (7) and (8), as well as Limit (5), indicate the cost and quality of each activity, taking into account the relevant execution mode. Limitations (1)–(3) indicate the time, cost, and overall quality of the project, respectively. The first chapter states that the project completion time (constraint (1)) can be calculated by summing the critical path activity times. Project cost will also simply be obtained from the sum of the costs of each project activity (constraint (2)). In constraint (3), a weight combination approach was used to determine the overall quality of the project. The weight of each activity indicates its importance and impact on the overall quality of the project. Usually, using more effective execution methods will reduce the time required to perform the activity. Still, more costs will have to be paid in connection with the use of more efficient resources and technologies. This means paying more for the quality of an activity.

Finding a solution to the problem of balancing time, cost, and quality involves determining the optimal combination of execution methods for all the activities that make up the project so that an optimal combination of time, cost, and quality is created for the project. Given the conflict in the intended objective functions, the multiobjective solution approach should solve the proposed model. Therefore, the next section examines the methods of achieving the goal and presents the desired method.

3.3.2. Multiple Attribute Utility Method. Researchers have developed a variety of methods for solving multiobjective problems. Some of these methods are:

(1) Hierarchical Method: in this method, the goals are arranged and optimized for their priority.

(2) Utility Method: in this method, a utility function is defined as a linear combination of objectives in which each of the objectives is given a separate weight. This function will be considered the target of the problem and will be optimized.

(3) Ideal Planning: in this method, an ideal level is defined for each goal. Here, the goal is to find a sequence that is as close as possible to the ideal value of the target. In this method, sometimes one of the goals is considered the main goal of the problem and the other goals are considered the constraints of the problem.
(4) Simultaneous or Pareto Method: in this method, innovative or superinnovative methods will be used to produce or estimate efficient and effective solutions.
(5) Interactive or Conversational Method: in this method, decision-makers state their priorities regarding several answers obtained from the solution method and then agree on some answers.

Each of the methods described has its advantages and disadvantages. Methods 1, 2, and 3 require more information and parameters. Methods 1 and 2 are practical but cannot produce good and efficient answers. Methods 3, 4, and 5 are more complete than the first two methods and have been further studied. In general, the method chosen to solve the problem depends on the characteristics of the problem and the space under discussion. This dissertation uses another method called multiple attribute utility. The multiple attribute utility technique was introduced in the eighteenth century by [43]. Multiple attribute utility is an analytical method for deciding problems based on several criteria. The application of the multiple attribute utility method in construction includes studies in procurement route selection [44] and evaluation of construction engineering performance [45].

Multiple attribute utility means the degree of utility associated with the output of each design. A plan may be chosen according to the priority of the decision-makers or the importance of each independent criterion or function. Each option or design that is evaluated is measured through multiutility functions that express each independent criterion in sequence and are formed using a set of weights. Each weight indicates the decision-maker's priority or the importance of each action. If there are $J \geq 1$ criteria for each option or scheme, the vector $Y = (y_1, \ldots, y_J)$ represents a vector of functions for that scheme. Therefore, the multiple utility combination for calculation in this scheme is calculated according to the following method.

$$U = \sum_{j=1}^{J} w_j u_j, \quad \left\{U \in [0,1]; u_j \in [0,1]\right\}, \tag{10}$$

where u_j, $(j = 1, 2, \ldots, J)$ is a function of the single-characteristic utility for the function j. w_j is the weight for z, and the sum of all weights is 1, i.e., $\sum_{j=1}^{J} w_j = 1$. Individual utility functions are classified into three types: exposure to risk, risk aversion, and neutral risk [46]. The neutral risk utility function is most commonly used and is calculated as follows:

$$u_j = a_j y_j + b_j, \tag{11}$$

where a_j and b_j are fixed values and can be calculated based on the best and worst performances whose level sizes reach the lowest level of zero and the highest level of 1, respectively. Considering the project criteria such as time, cost, and quality in relation to the combination of construction methods, equations for calculating single-characteristic values for time, cost, and quality of a project are expressed as follows:

$$\begin{aligned} u_D &= \frac{D^+ - D}{D^+ - D^-}, \\ u_C &= \frac{C^+ - C}{C^+ - C^-}, \\ u_Q &= \frac{Q - Q^-}{Q^+ - Q^-}. \end{aligned} \tag{12}$$

In the above relationships, D, C, and Q represent time, cost, and quality of the project, respectively. D^+ and D^- represent the largest and smallest project times, respectively. C^+ and C^- also represent the highest and smallest costs of the whole project, respectively. Q^+ and Q^- represent the maximum and minimum overall quality of the project, respectively. If the weights of the three criteria are equal to w_D, w_c, and w_Q, then the desirability of the composite characteristic is obtained through the following equation. The optimal design is the design that has the most desirable composite feature:

$$U = w_D u_D + w_C u_C + w_Q u_Q. \tag{13}$$

Considering the concepts presented in the previous section, the appropriate modeling of the multiple attribute utility method for the problem of time, cost, and quality balance will be as follows.

$$\begin{aligned} &\max U = w_D u_D + w_C u_C + w_Q u_Q, \\ &\quad u_D = \frac{D^+ - F_n}{D^+ - D^-}, \\ &\quad u_C = \frac{C^+ - \sum_{j=1}^{n} C_j}{C^+ - C^-}, \\ &\quad u_Q = \frac{\sum_{j=1}^{n} w_j \cdot Q_j - Q^-}{Q^+ - Q^-}, \\ &\sum_{m=1}^{m_j} x_{jm} = 1, \quad \forall j = 1, 2 \ldots, n, \\ &\quad D_j = \sum_{m=1}^{m_j} x_{jm}.d_{jm}, \quad \forall j = 1, 2 \ldots, n, \\ &\quad F_j \geq F_k + D_j, \quad \forall j = 1, 2 \ldots, n, \forall k \in P_j, \\ &\quad C_j = \sum_{m=1}^{m_j} x_{jm}.c_{jm}, \quad \forall j = 1, 2 \ldots, n, \\ &\quad Q_j = \sum_{m=1}^{m_j} x_{jm}.q_{jm}, \quad \forall j = 1, 2 \ldots, n, \\ &\quad x_{jm} \in \{0, 1\}, \quad \forall j = 1, 2 \ldots, n, m = 1, 2, \ldots, m_j, \\ &\quad F_j \in R, \quad \forall j = 1, 2 \ldots, n. \end{aligned} \tag{14}$$

As stated in the previous sections, the performance criteria of time, cost, and quality related to the different implementation methods of each activity are collected and calculated by project managers or engineers based on past or current experiences or based on expert opinion. Of course, it is not possible to express these parameters, especially the quality of an activity, in precise and specific values. In addition, due to environmental conditions, especially the mentality of managers and engineers in estimating various parameters, project activities' evaluation, or performance criteria is expressed in an uncertain, vague, and inaccurate manner. On the other hand, fitting and estimating the relationship between the implementation method of activity and the performance criteria related to that activity can be due to the uniqueness of the project or its activities and other factors such as environmental conditions, equipment specifications, staff efficiency, supply conditions, and coordination problems. Therefore, the existence of uncertainty and ambiguity in evaluating and expressing the performance of each project activity and the project as a whole is evident and unavoidable.

Therefore, as a development of the present models and also to investigate the problem of time, cost, and quality balance due to the ambiguity and uncertainty in determining and expressing the performance criteria of each project activity (time, cost, and fuzzy quality balance problem), the multiattribute utility technique will be studied in the next section.

4. Adjust the Parameters Using the Taguchi Method

Under the topics discussed in the previous section, the design method of Taguchi experiments with a smaller number of tests leads to a reasonable cost and time savings. It provides the data needed to analyze and achieve the optimal conditions. This advantage has caused the attention of many researchers in recent years to adjust the parameters required by their proposed algorithms [47–49]. In this dissertation, by the above research, the best parameters and operators for implementing algorithms are obtained using this method. For more details on applying the Taguchi experimental design method to parameterization, see [49].

4.1. Select the Appropriate Orthogonal Array. First, how to use the Taguchi method and select the appropriate orthogonal array in this study with one of the methods developed in this dissertation (PSO) is described. This example also demonstrates the effectiveness of the Taguchi method in saving cost and time compared to the complete factorial experiment design method.

In this algorithm, using preliminary experiments for the parameters and operators mentioned above, there are four 3-level factors and one 5-level factor. Factors and their levels are shown in Table 2. In total, to implement the algorithm to solve the problem, $81 \times 10 \times 10 \times 5 \times 10$ experiments with the complete factorial method are required, which is equal to 12150 experiments.

Table 2: Candidate factors and levels in the group particle optimization algorithm (PSO).

Factors	PSO symbol	PSO levels
C2	A	A(1): 0.6 A(2): 0.75 A(3): 0.9
Iteration	B	B(1): n B(2): $2 * n$ B(3): $3 * n$
W	C	C(1): 0.85 C(2): 1.2 C(3): 1.4
Population size	D	D(1): $0.5 * n$ D(2): n D(3): $2 * n$
C1	E	E(1): 0,9 E(2): 1 E(3): 1.1 E(4): 1.2 E(5): 1.4

Due to the importance of reducing cost and time in the implementation of algorithms, especially in scheduling the implementation of this approach, designing experiments is not cost-effective, so Taguchi fractional factorial designs will effectively save time and money. Taguchi standard and simple designs have been used in fewer experiments at the optimum point and in estimating the effect of important factors. In the first step, the required number of degrees of freedom must be calculated to implement the Taguchi method to fit the appropriate orthogonal array. In this case, one degree of freedom is required for the total average, four degrees of freedom for the five-level factor, and two degrees of freedom for each three-level factor (in general, for four two-level factors, $8 = 4 = 2$ degrees of freedom). Therefore, the sum of the required degrees of freedom is equal to

$$(2 \times 4) + 4 + 1 = 13. \quad (15)$$

Therefore, an array with at least 13 rows must be selected. According to the Taguchi standard orthogonal arrays, it is clear that in orthogonal arrays L16 and L18, this condition is established that the L18 array is selected according to the levels of factors. Using the L18 array is that the number of parameters and array levels do not match the PSO algorithm. Therefore, this array is modified with matching techniques. Because in the proposed particle optimization method, there are four 3-level parameters, and in the L18 array, there are six three-level parameters, the two columns of the L18 array must be removed. Also, using the virtual level technique, the six-level column is converted to a five-level parameter, one of which must be executed twice in L18 in this column, and the fifth level is selected.

In the virtual surface technique, the accuracy of repeated surfaces is twice the parameter accuracy of other levels. When modifying arrays, the point to note is that the modified array remains orthogonal. Tables 3 and 4 show the structure of the L18 array and the modified array structure for the proposed particle mass optimization algorithm. The total number of implementations of the previous example problem using the Taguchi method will be 540 = 10 × 18 × 10 times, and if 12150 has been performed using the full-factorial test design method, 11610 = 540–11250 tests have been saved in time and cost.

Before implementing the algorithms, appropriate parameters and candidate levels were first selected for all algorithms using preliminary experiments to solve the problem under study. Then, using the method mentioned above, the appropriate orthogonal arrays are selected for execution according to these factors (parameters and operators). Finally, with the implementation of each algorithm, the best factors were obtained, which will be explained in the following sections on how to select the best parameter.

It should also be noted that, in most articles and previous researches, the parameters and operators of meta-innovative methods with which the algorithm presented in the research are compared, either user-defined or adapted from previous research, and only the parameters and operators of the proposed algorithm are adjusted. The quality of the answer of an algorithm and its optimal parameters depends largely on the type of objective function and the problems used in it [50]. For this reason, in this study, for the conditions to be equal for all the proposed algorithms and other algorithms, the Taguchi method and parameter adjustment are applied to all algorithms.

4.2. Factor Adjustment and Levels of Each Factor Model-Solving Algorithms. To solve the problem, two meta-heuristic algorithms, including group particle optimization (PSO) and artificial bee colony (ABC) optimization, are compared. For each of these algorithms, appropriate parameters have been selected using preliminary experiments shown in Tables 2 and 5 that the best and best combination of parameters and operators should be selected using the Taguchi method. The meaning of n in Table 6 is the number of project activities in each problem instance.

4.3. Creating Sample Problems. According to the article mentioned in the first section, sample problems are created completely randomly, which is used to evaluate the performance of the proposed algorithms. These issues include 10 combinations of the number of activities () and the maximum number of executable modes (). To be more confident and eliminate random factors, each issue was run independently 3 times. The independence of each repetition means that the results after each performance are completely independent and not interdependent. To perform the experiments, all the algorithms used in this dissertation were programmed with MATLAB software on a personal computer with a 2.27 GHz 5i core microprocessor and 4.00 GB memory and then executed.

4.4. Selecting the Best Factors. In each test run, the value of the objective function obtained must be converted according to the Taguchi method to the signal-to-noise ratio, a response variable, and analyzed according to its changes.

Table 3: L18 orthogonal array suitable for particle mass optimization algorithm.

Trial	A	B	C	D	E	F	G
1	0	0	0	0	0	0	0
2	0	0	1	1	2	2	1
3	0	1	0	2	2	1	2
4	0	1	2	0	1	2	3
5	0	2	1	2	1	0	4
6	0	2	2	1	0	1	5
7	1	0	0	2	1	2	5
8	1	0	2	0	2	1	4
9	1	1	1	1	1	1	0
10	1	1	2	2	0	0	1
11	1	2	0	1	2	0	3
12	1	2	1	0	0	2	2
13	2	0	1	2	0	1	3
14	2	0	2	1	1	0	2
15	2	1	0	1	0	2	4
16	2	1	1	0	2	0	5
17	2	2	0	0	1	1	1
18	2	2	2	2	2	2	0

Table 4: Modified array L18 for particle mass optimization algorithm.

Trial	A	B	C	D	E
1	0	0	0	0	0
2	0	0	1	1	1
3	0	1	0	2	2
4	0	1	2	0	3
5	0	2	1	2	4
6	0	2	2	1	4
7	1	0	0	2	4
8	1	0	2	0	4
9	1	1	1	1	0
10	1	1	2	2	1
11	1	2	0	1	3
12	1	2	1	0	2
13	2	0	1	2	3
14	2	0	2	1	2
15	2	1	0	1	4
16	2	1	1	0	4
17	2	2	0	0	1
18	2	2	2	2	0

Table 5: Factors and candidate levels in artificial bee colony (ABC) optimization algorithm.

Factors	HS Symbols	HS levels
Number of bee	NP	NP(1): n NP(2): $2 * n$ NP(3): $3 * n$
Abandoned limit	LIM	LIM(1): 50 LIM(2): 70 LIM(3): 100
Iteration	INT	INT(1): n INT(2):$2 * n$ INT(3): $3 * n$

Table 6: Modified Taguchi L9 orthogonal array for artificial bee colony optimization algorithm.

Trial	NP	LIM	INT
1	0	0	0
2	0	1	1
3	0	2	2
4	1	0	1
5	1	1	2
6	1	2	0
7	2	0	2
8	2	1	0
9	2	2	1

$$\frac{S}{N_s} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right). \quad (16)$$

In Taguchi's method, the S/N ratio is a ratio variable to which the objective function is converted in each execution to make a decision. In this research, according to the selected S/N_s ratio appropriate to the nature of the problems of this research, the maximum S/N_s ratio for each factor in each algorithm is selected as the optimal factor.

4.4.1. Selecting the Optimal Factors of Model-Solving Algorithms. The results of the whole implementation of the model-solving algorithms by designing Taguchi experiments to adjust the parameters are shown as S/N_s ratio in Figures 2 to 9.

According to the above figures, the best factors for the final implementation of the algorithms for solving the model are given in Tables 7 and 8.

4.5. Computational Results. Therefore, the use of methods is meta-innovative, so first, with the parameters and optimal operators of each algorithm obtained by the Taguchi method in the previous section, the results of the implementation of the algorithms are presented on the sample problems created in this chapter. In the sample of problems created to perform experiments by changing dimensions such as the number of project activities and execution modes of each activity, due to differences and nonuniformity of the scale of the value of the objective functions, the percentage of relative deviation in (17) has been used to compare algorithms.

$$\text{RPD} = \frac{\text{Max}_{\text{sol}} - \text{ALG}_{\text{sol}}}{\text{Max}_{\text{sol}}} \times 100. \quad (17)$$

In the results section, we compare the performance of algorithms for the size of the problem, which changes with an increasing number of activities. That ALGsol is the result of the algorithm, and Maxsol is the maximum amount of answers. In this ratio, the lower the RPD, the better the response quality and performance of the algorithm. After summarizing the RPD results, the performance of the algorithms is plotted in the form of graphs and tables.

4.5.1. Results of Implementation of Algorithms. The proposed algorithms for solving the model were described in the previous sections. The RPD results obtained from implementing the studied algorithms are shown in Table 9. Table 9 shows the high-quality performance of the particle mass optimization algorithm with an average of 0.015 in solving the problem of time, cost, and fuzzy quality balance developed in the previous chapter. Comparing the two proposed particle mass and artificial bee colony algorithms, it can be seen that the PSO algorithm performed better. Figure 10 also shows a comparison diagram of the two proposed algorithms.

Since different combinations of parameters are involved in the implementation of an algorithm, different quality answers can be achieved. In this section, the topics related to

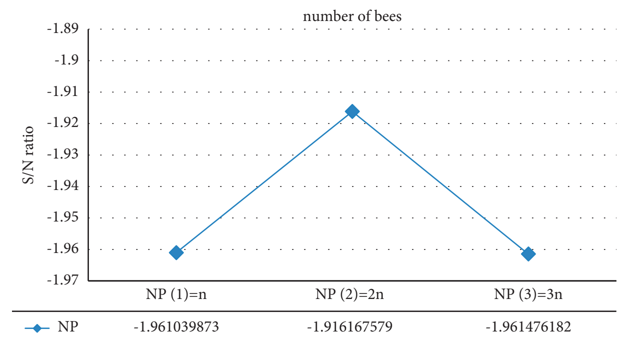

Figure 2: Graph of average S/N ratio for each level of NP factor of ABC algorithm in model solving.

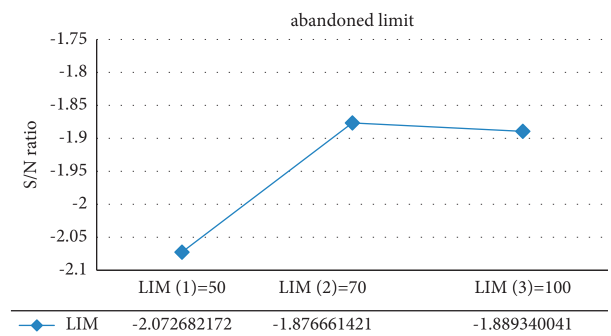

Figure 3: Graph of the average S/N ratio for each level of the ABC algorithm lim factor in model solution.

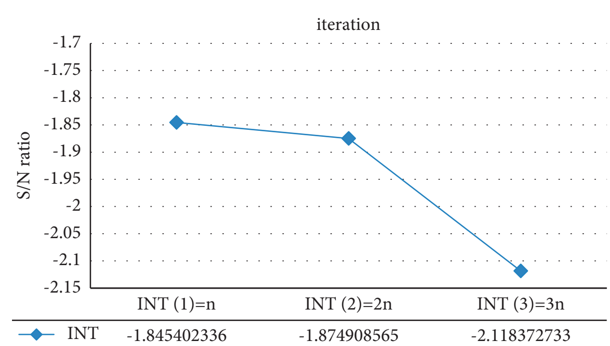

Figure 4: Graph of the average S/N ratio for each level of the int factor of the ABC algorithm in solving the model.

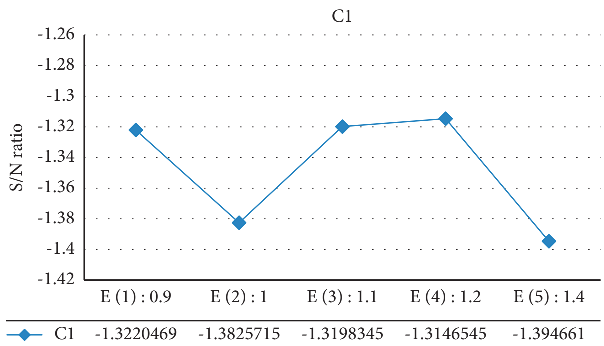

Figure 5: Graph of average *S*/*N* ratio for each level of factor C1 of PSO algorithm in model solution.

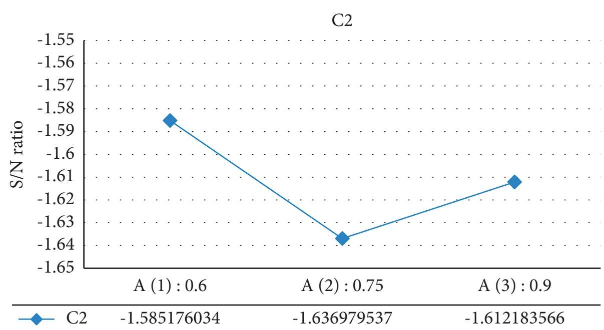

Figure 6: Graph of average *S*/*N* ratio for each level of factor C2 of PSO algorithm in model solving.

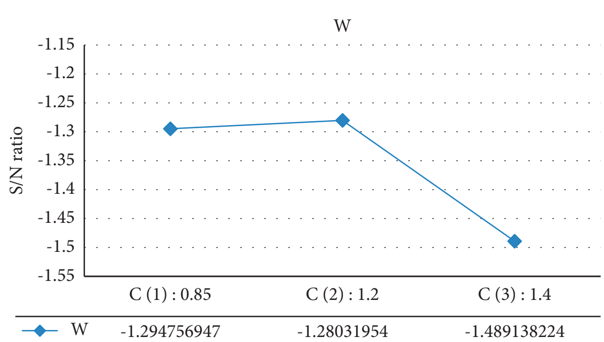

Figure 7: Graph of average *S*/*N* ratio for each level of factor W of PSO algorithm in model solution.

setting the parameters of the algorithm were presented. After using the previous research and preliminary experiments in this issue, the appropriate values of the parameters and operators of the algorithms and levels of each were determined, and the appropriate arrays of the design method of Taguchi experiments for execution were determined.

In this regard, first, how to create sample problems was described. With this example, the optimal-level problems of the parameters of 2 meta-heuristic algorithms were obtained by the Taguchi experimental design method. The results of comparing the algorithms in most of the samples show better performance of the particle mass optimization method. In the innovative oven methods, both Taguchi and

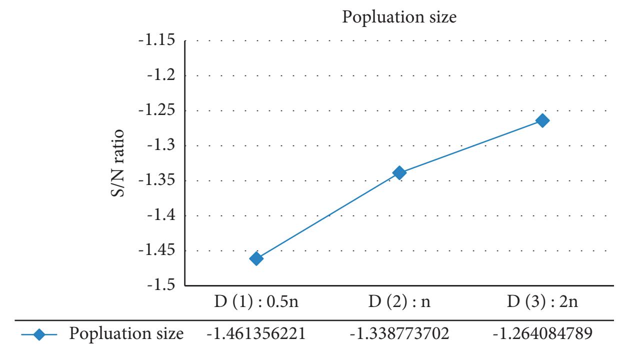

Figure 8: Graph of the average *S*/*N* ratio for each level of the POPSIZE factor of the PSO algorithm in solving the model.

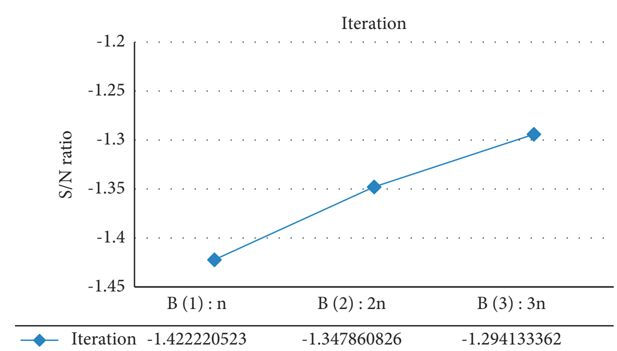

Figure 9: Graph of average *S*/*N* ratio for each level of INT factor of PSO algorithm in model solving.

Table 7: Optimal parameters and operators of ABC algorithm.

Factors	Optimum level
NP	2n
LIM	70
INT	N

Table 8: Optimal parameters and operators of PSO algorithm.

Factors	Optimum level
C_2	0.6
ITERATION	3n
W	1.2
POPSIZE	$2n$
C_1	1.2

restart phase methods were used to improve the performance of these methods.

5. Managerial Insight and Practical Implication

Researchers in previous studies have used innovative and ultra-innovative methods to solve these problems to avoid further complexity. The development of accurate methods is also very important because they are the only valid scale by

Table 9: Mean relative deviation percentage (RPD) of algorithms for each combination of sample problems in problem solving.

Average	10	9	8	7	6	5	4	3	2	1	Problem number
0.165	0.198	0.203	0.168	0.170	0.139	0.143	0.175	0.152	0.166	0.143	ABC
0.015	0.027	0.030	0.021	0.009	0.018	0.016	0.005	0.003	0.012	0.009	PSO

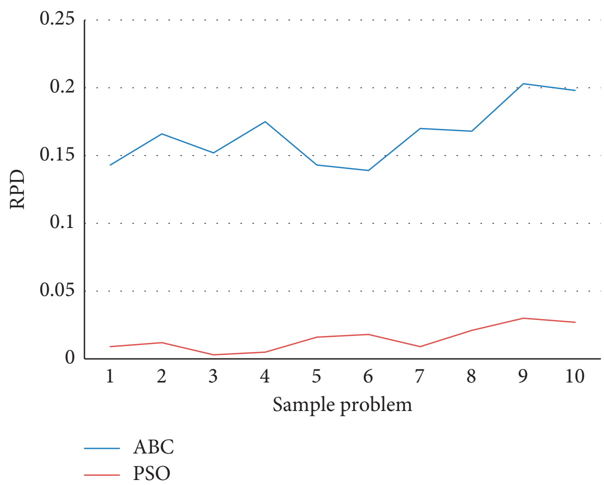

Figure 10: RPD diagram of the performance of the algorithms for each sample problem.

which innovative and meta-innovative methods can be evaluated. In this article, considering the quality coefficient of the project as one of the pillars of the project, it examines the cost-time exchange. In recent years, new methods of cost-time balance have been proposed. In project scheduling calculations, the first time to complete the last activity is the project delivery date. Project completion time is generally reduced by revising network logic or shortening activities at a higher cost. As the duration of activities decreases, the quality of each move, i.e., the proximity of the project delivery products to the expectations of the employer or the customer, decreases. In the discussion of the balance between the three functions of cost, time, and project quality, cost sensitivity analysis is performed against changes during the duration of the activity, which aims to obtain the best combination of reducing the time of activities. In this way, the total cost of the project is minimized and the quality of the whole project is maximized.

6. Conclusion

The general approach of this dissertation in dealing with the issue of uncertainty in the management and planning environment of project activities has been different from previous research. This means that instead of considering the expected value of various parameters of project activities during modeling, fuzzy number theory has been used as a tool to analyze and optimize the planning and management of project activities.

Accordingly, in the third part, the project's balance of time, cost, and quality are modeled as a fuzzy model. In the designed model, the performance measures of each activity, such as time, cost, and quality, are considered exemplary or trapezoidal fuzzy numbers. It is assumed that there is no interruption in the implementation of various project activities, and each project activity can be implemented in a small number of different implementation methods. Due to the multiobjective nature of the problem ahead, the multiattribute utility technique has been used to calculate the desirability of each implementation method in terms of fuzzy time, cost, and quality.

Although the issue of balancing time, cost, and quality of project activities is one of the most important issues in the field of project planning and management, very little research has examined this type of issue. In many studies, the goal is to minimize the overall execution time of the project. However, for many project managers, balancing the performance metrics of a project is very important. Another key hypothesis that has been considered in less research is the focus of the present study on solving the problem of fuzzy time, cost, and quality balance through two meta-heuristic algorithms of particle mass optimization and fuzzy multiobjective artificial bee colony.

Data Availability

All data used to support the findings of the study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

The Analysis of the Role of Bullwhip Effects on the Four-Level Supply Chain in Industry Using Statistical Methods

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Nowadays, regarding the technology development and communication means, supply chain management has gained special significance among different industries. The impact of bullwhip is one of the factors that could lessn the supply chain efficiency and increase the cost and delivery time of products and services. In this study, we explored the demand forecasting in supply chain, a four-level chain of retailers, wholesalers, manufacturers, and suppliers. Each level of the chain forecasted demand by moving average method, exponential smoothing, multilayer perceptron artificial neural network, and regression. Also, we provide a hybrid model based on statistics and mathematics to reduce the effect of bullwhip. For this purpose, at first, the supply chain simulation was performed. The results were then evaluated applying analysis of variance and the best combined model to reduce the amount of bullwhip effect was introduced. The model of this research could be useful for other studies. Finally, forecast for retail demand using the regression model; wholesale demand using the exponential smoothing model; manufacture demand using the neural network; and supplier demand using the moving average method have been done.

1. Introduction

In the present study, the effect of combined use of various forecasting methods on the bullwhip effect in a four-level supply chain, including retailers, wholesalers, manufacturers, and suppliers, is investigated. Although a similar issue has been explored in many previous research studies, considering the nature of supply chain components, it is more consistent with reality [1]. For this purpose, first, the supply chain was simulated. The retailer demand received from end customers is assumed to be a Poisson process with rate. This distribution has been selected according to several other research studies that have used this distribution as a demand model in the supply chain [2, 3]. This choice is rooted in the nature and specificity of the Poisson distribution in depicting counting processes. In fact, a look at the process of customers entering the system and registering their demand shows the fact that the process of product demand is a counting process that was well illustrated by the Poisson distribution. This feature has caused more than half of the research studies related to multilevel systems to use this distribution as a demand model [4, 5].

For this purpose, main research question is as follows:

(i). For this purpose, main research question is how can the effect of a bullwhip on supply chain efficiency be measured?

Therefore, main contribution of the paper is as follows:

(i) Predict demand in a four-level supply chain with retailers, wholesalers, manufacturers, and supplier elements.

(ii) Provide a hybrid model based on statistics and mathematics to reduce the effect of bullwhip.

The rest of the article is organized as follows: in Section 2, we present a literature review. In Section 3, we present research methodology. In Section 4, we present results of the paper finally, and in Section 5, we present overall conclusion and further research for future study.

2. Literature Review

In an article with a simulation approach and repeated measurements, Huang et al. [6] presented a spatiotemporal Markov model (STMM) with the probability chain adjustment (STMMPC) to predict states of inventory variation and analyze inventory variation propagation in multistage steel production processes. Jackson I. [7] demonstrated how deep reinforcement learning agents based on the proximal policy optimization algorithm can synchronize inbound and outbound flows if end-to-end visibility is provided. The paper concludes that the proposed solution has the potential to perform adaptive control in complex supply chains. Furthermore, the proposed approach is general, task unspecific, and adaptive in the sense that prior knowledge about the system is not required. Yang et al. [8] modeled the severe effects of seasonal demand in the multistage supply chain and reduced the bullwhip effect, which could not be easily achieved with analytical approaches. Also, she compared the two neural network methods with the ARIMA method and concluded that the neural network method reduces the bullwhip effect. Durán Peña et al. [9] carried out a literature review to determine the causes of the bullwhip effect and the supply chain's quality factors of this phenomenon's perishable products. Updating the demand, the level of deterioration of the product, and the number of intermediaries is the causes of the bullwhip effect most investigated. On the other hand, the product's safety and the quality of the information are the quality factors of the chain of supplies of perishable products more researched. According to this study, important future research will be addressed by causes of human behavior that affect the bullwhip effect in the perishable goods supply chain. Fu et al. [10] investigated the behavioral operations effect in production inventory decision of supply chain consisting of one manufacturer and one buyer, and analyze how the unfairness concerns impact the decision of production inventory in a supply chain system. For this purpose, first a model without the buyer's unfairness concern is established; then, advantage unfairness concern and disadvantage unfairness concern behavior of the buyer are taken into account in the production inventory system. The authors analyze how advantage unfairness concern and disadvantage unfairness concern impact the optimal decisions and channel coordination. Trenggonowati et al. [11] calculated the value of bullwhip effect as well as designing improvements to minimize the bullwhip effect. Based on the research results, the index value of bullwhip effect on longitudinal pipe products is 1.06 and the index value of bullwhip effect on spiral pipe products is 0.80. The improvement design to minimize the phenomenon of bullwhip effect is to build an integrated information system for the customer, manufacturer, and supplier. Zhao et al. [12] employed system dynamics (SD) model to explore the effect of single strategy and combined scenarios on mitigating inventory amplification, i.e., bullwhip effect (BE) in three-echelon SC. Novel scenario simulation is designed to stimulate recovery activities of electronic waste, decrease solid material depletion, and promote clean production. Main thread is as follows: establishing the SD model in line with practical operation mechanism, testing the robustness of model, emulating the effect of single strategy and combined scenarios on mitigating BE, and finally proposing optimal strategies on the optimization of green SC. Cannella et al. [13] presented the mathematical formulation of the supply chain model and conducted a numerical simulation assuming different levels of errors. Results clearly show that Inventory Record Inaccuracy strongly compromises supply chain stability, particularly when moving upwards in the supply chain. Important managerial insights can be extracted from this analysis, such as the role of "benefit-sharing" strategies in order to guarantee the advantage of investments in connectivity technologies. Jaipuria and Mahapatra [14] integrated approach of discrete wavelet transform (DWT) analysis and artificial neural network (ANN) denoted as DWT-ANN is proposed for demand forecasting. Initially, the proposed model is tested and validated by conducting a comparative study between Autoregressive Integrated Moving Average (ARIMA) and proposed DWT-ANN model using a data set from the open literature. Furthermore, the model is tested with demand data collected from three different manufacturing firms. Bray and Mendelson [15] investigated the effect of information exchange between supply chain levels on its bullwhip effect. Bhattacharya and Bandyopadhyay [16] reviewed studies on the factors affecting the effect of bullwhip. Hayya C. [17] investigated the effect of random preparation times, information sharing, and quality of shared information on bullwhip effect. Machuca and Barajas [18] also studied the effect of electronic data exchange on reducing the bullwhip effect and the average cost of inventory using Internet simulation software. Kelepouris et al. [19] investigated the effect of replenishment and information sharing parameters on bullwhip effect. Marko and Rusjan [20] also studied the effect of replenishment policies on this effect. Agrawal et al. [21] investigated the effect of preparation time and information sharing on bullwhip.

One of the factors that many experts believe in its effect on bullwhip is the use of supply chain links by various forecasting methods. One of the factors that many experts believe in its effect on bullwhip effect is the use of supply chain links by various forecasting methods. In this regard, extensive studies have been conducted on the effect of forecasting methods on bullwhip effect such as Chen et al. [22] that studied and compared the effect of two methods of exponential smoothing and moving average on bullwhip effect in a simple two-level supply chain including a retailer and a manufacturer. Chen et al. [23] also investigated the effects of two factors demand forecasting and order supply time on bullwhip effect in a two-level supply chain and generalized the result to multilevel chains. Zhang X. [24] investigated the effect of forecasting methods on bullwhip effect in a simple inventory supply system and concluded

Table 1: Paper classification.

Scope	Author	Year of publication	Goal	Model
Simulation	Huang et al.	2022	Predict state of inventory variation	Spatiotemporal Markov
	Jackson	2022	Deep reinforcement learning agents	Proximal policy optimization algorithm
	Yang et al.	2021	Measured effects of seasonal demand	Artificial neural network
	Fu et al.	2021	Investigation of the behavioral effect in production inventory	Mathematical model
	Zhao et al.	2018	Optimization green supply chain	System dynamic
Forecasting	Ivanov and Sokolov	2013	Presentation of perspective supply chain operation	Mathematical model

Table 2: Scenarios of forecasting methods in the four-level supply chain.

	Retailer	Wholesaler	Manufacturer	Supplier
Scenario 1	Linear regression	Exponential smoothing	Neural network	Moving average
Scenario 2	Linear regression	Exponential smoothing	Moving average	Neural network
Scenario 3	Linear regression	Neural network	Exponential smoothing	Moving average
Scenario 4	Linear regression	Moving average	Exponential smoothing	Neural network
Scenario 5	Linear regression	Moving average	Neural network	Exponential smoothing
Scenario 6	Linear regression	Neural network	Moving average	Exponential smoothing
Scenario 7	Exponential smoothing	Linear regression	Neural network	Moving average
Scenario 8	Exponential smoothing	Linear regression	Moving average	Neural network
Scenario 9	Exponential smoothing	Neural network	Linear regression	Moving average
Scenario 10	Exponential smoothing	Moving average	Linear regression	Neural network
Scenario 11	Exponential smoothing	Moving average	Neural network	Linear regression
Scenario 12	Exponential smoothing	Neural network	Moving average	Linear regression
Scenario 13	Neural network	Exponential smoothing	Moving average	Linear regression
Scenario 14	Neural network	Exponential smoothing	Linear regression	Moving average
Scenario 15	Neural network	Moving average	Exponential smoothing	Linear regression
Scenario 16	Neural network	Linear regression	Moving average	Exponential smoothing
Scenario 17	Neural network	Linear regression	Exponential smoothing	Moving average
Scenario 18	Neural network	Moving average	Linear regression	Exponential smoothing
Scenario 19	Moving average	Neural network	Exponential smoothing	Linear regression
Scenario 20	Moving average	Neural network	Linear regression	Exponential smoothing
Scenario 21	Moving average	Exponential smoothing	Neural network	Linear regression
Scenario 22	Moving average	Linear regression	Neural network	Exponential smoothing
Scenario 23	Moving average	Linear regression	Exponential smoothing	Neural network
Scenario 24	Moving average	Exponential smoothing	Linear regression	Neural network

that forecasting methods are effective on bullwhip effect. Barlas and Gunduz [25] mentioned uncoordinated use of different levels of the chain in forecasting methods as one of the structural roots of bullwhip effect in supply chains. Ivanov and Sokolov [26] presented the first to address the operative perspective of the supply chain dynamics domain. The methodology of this conceptual paper is based on the business and technical literature analysis and fundamentals of control and systems theory. In contributing to the existing studies in this domain, the paper proposes a possible systemization and classification of related terminology from different theoretical perspectives, and important practical problems. For the supply chain dynamics domain, the paper identifies and groups possible problem classes of research, corresponding quantitative methods, and describes the general mathematical formulations. Constantino et al. [27] attempt to evaluation by investigating the interaction of collaboration and coordination in a four-echelon supply chain under different scenarios of information sharing level. In Table 1, we categorized previous studies according to goal and research methodology.

2.1. Research Gap. According to the above, there is no study that can reduce the effect of bull whip on the supply chain using statistical-mathematical analysis simultaneously. In general, only mathematical prediction tools have been used. For this purpose to fill gap in this research, demand forecasting in a four-level supply chain that has retail, wholesale, manufacturer, and supplier elements is done by presenting a hybrid model based on statistics and mathematics.

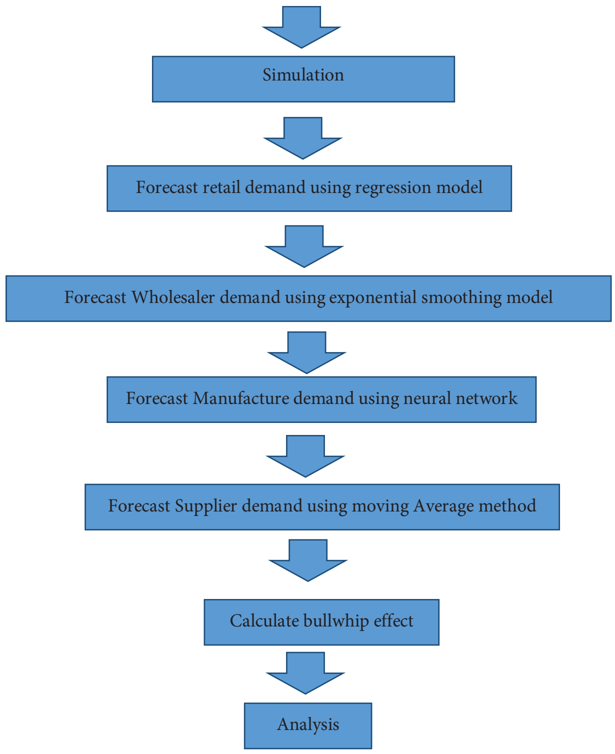

Figure 1: Research framework.

3. Methodology

In terms of purpose, it is fundamental and applied research because it is research that finds the best forecasting scenario to reduce the bullwhip effect of in the supply chain and uses the central limit theorem to prove its claim and uses it in a case study and is quantitative in nature.

3.1. Problem Statement. The components of the chain use four methods of moving average, exponential smoothing, regression, and neural network to forecast their demand assuming that none of the components use the same method. Therefore, 24 different combinations of the four available forecasting methods will be investigated. Because the retailer is the lowest level of the chain, it is related to the actual demand of the customers; therefore, the forecasting this level of the chain is based on the actual demand of the customers. At the second level of the chain, the wholesaler is related to the retailer; therefore, the amount of the retailer order is considered as wholesale demand. At the third level of the chain, the manufacturer is associated with the wholesaler. In fact, wholesale order is considered as the demand of this level of the chain. At the highest level of the studied chain, the supplier is associated with the manufacturer. In other words, the amount of the manufacturer's order is considered as the demand of this level of the chain. Therefore, the supplier tries to forecast the demand for the next period based on the previous orders of the manufacturer. First, with the obtained hypotheses, we randomly generate a demand sample with the Poisson process. Then, according to the two-bin ordering policy, the amount of orders at each level is obtained as high-level demand and forecasting is performed. The 24 proposed scenarios are given in Table 2.

Table 3: Random demand data for customers.

Period	Random demand
1	5
2	1
3	0
4	1
5	1
6	2
7	2
8	2
9	3
10	2
11	0
12	3
13	1
14	2
15	2
16	2
17	4
18	3
19	4
20	3
21	4
22	5
23	7
24	2
25	5
26	4
27	4
28	5
29	5
30	4
31	6
32	6
33	6
34	7
35	2
36	8

Finally, the bullwhip effect in the scenarios was calculated and compared using Minitab, Excel, MATLAB software, and statistical tests, and then, the best scenario was introduced as the lowest amount of bullwhip effect to be used in other 4-level supply chains. Then, the best model introduced in Zarbal Company was used and the result was a reduction in the bullwhip effect of Zarbal Company.

For this purpose, the effect of applying various forecasting methods in a four-level supply chain on bullwhip effect is investigated in this study. The main objective of this project is to provide an approach and model for analyzing various scenarios and evaluating their effects on supply chains. In this study, bullwhip effect is considered as one of the most important performance indicators of supply chain. The demand of four supply chain levels was calculated in such a way that in the forecasting scenarios, none of the supply chain levels were allowed to choose the same method for forecasting. Taking into account this assumption, 24 (four factorial modes) forecasting scenarios were formed in

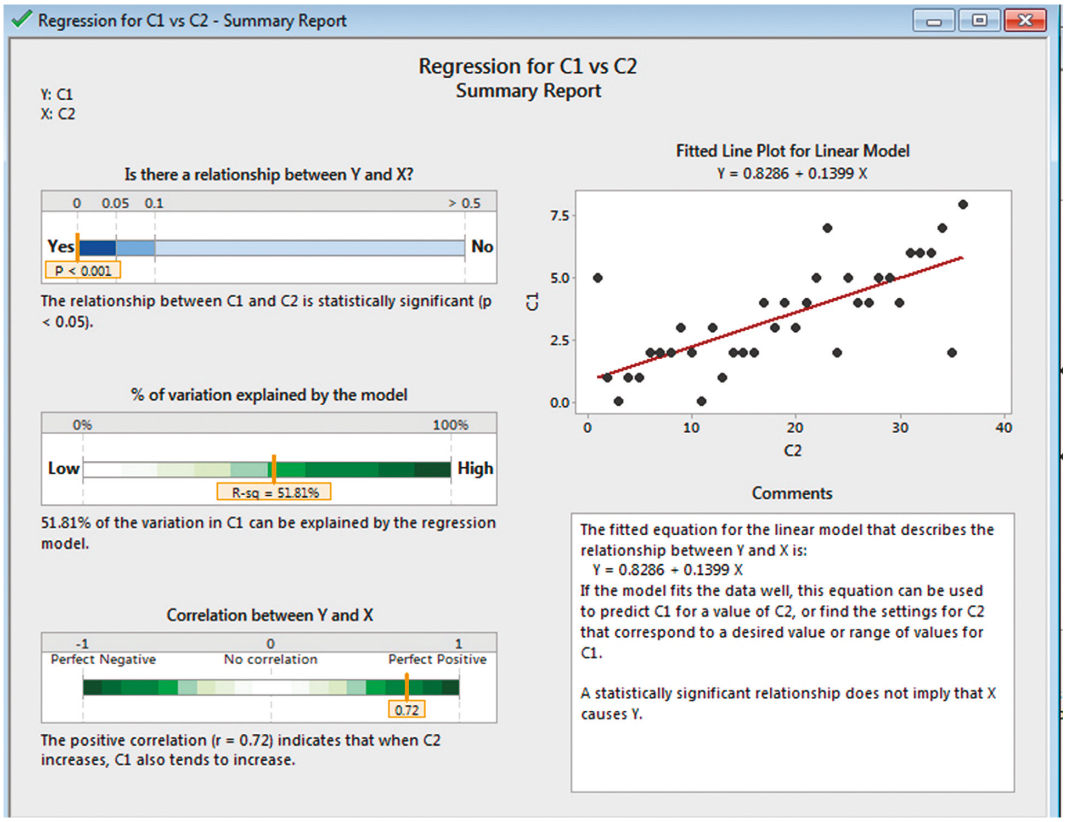

Figure 2: Correlation diagram of customer demand.

which the chain levels forecasted by moving average, linear regression, exponential smoothing, and multilayer perceptron neural network. In Figure 1, research methodology framework is shown.

3.2. Simulation. First, the intended supply chain was simulated and by Minitab 17 software, 36 random numbers were generated with Poisson distribution with parameter 4, and the random values of which are shown in Table 3.

Then, according to Scenario 1, the steps of demand forecasting and ordering were formed by the two-bin method (2 and 6).

3.3. Forecasting Retail Level Demand Using Regression Method. According to Figure 2, the correlation hypothesis between random data was confirmed; then, the retailer demand was forecasted using the Minitab and regression method. Because $p-\text{value} < 0.5$, the value of the null hypothesis is rejected and the two variables X and Y are correlated:

$$\begin{cases} H_0: \rho = 0 \\ H_1: \rho \neq 0 \end{cases}. \quad (1)$$

The formula $Y = 0.8286 + 0.1399\,X$ shows the regression equation performed to forecast retail level demand. The two-bin ordering system used in Table 4 is performed using two bins (boxes). The capacity of the smaller bin is equal to the amount of inventory required at the order point (equivalent to 2 units). When the products arrive at the warehouse, bin number 2 (smaller bin) is always filled first and then the rest of the inventory is kept in bin number 1 (total volume of the warehouse). Consumption starts from bin number 1, and when the inventory of this bin is finished, the inventory has practically reached the order point. At this time, in order to resupply the products, the order will be issued at a fixed and determined amount. Upon receipt of the ordered products, consumption will take place from bin number 2. As stated in previous chapters, inventory quantities are zero at the beginning of the period, and since the ordering system is two-bin (6 and 2), in the first stage, it needs to be ordered in a quantity that, in addition to meeting the expected demand, fills the maximum warehouse volume. Since the total demand forecasting of stages 2, 3, and 4 in Table 3 does not cause the inventory to reach less than 2 units, the order quantities of these periods are zero; therefore, orders are made in way that the amount of warehouse inventory should not be less than 2 units (smaller bin) and also the amount of inventory should not exceed 6 units. This logic of two-bin ordering system (6 and (2) was defined in Excel software for all levels of the supply chain so that all levels of the supply chain can order with this ordering system. Table 4 shows retail demand forecasting value using regression formula, retail order quantities, and retailor inventory over different time periods.

3.4. Forecasting Wholesaler Level Demand Using Exponential Smoothing Method. Using the quantities of retailer order by the exponential smoothing method and coefficient $\alpha = 0.33$,

Table 4: Demand forecasting and retail order by the regression method.

Period	Demand	Order	Warehouse
1	0.97	6.97	6
2	1.11	0	4.89
3	1.25	0	3.64
4	1.39	0	2.26
5	1.53	5.27	6
6	1.67	0	4.33
7	1.81	0	2.52
8	1.95	5042	6
9	2.09	0	3.91
10	2.23	4.32	6
11	2.37	0	3.63
12	2.51	4.87	6
13	2.65	0	3.35
14	2.79	5.43	6
15	2.93	0	3.07
16	3.07	5.99	6
17	3.21	0	2.79
18	3.35	6.55	6
19	3.49	0	2.51
20	3.63	7.11	6
21	3.77	0	2.23
22	3.91	7.67	6
23	4.05	4.05	6
24	4.19	4.19	6
25	4.33	4.33	6
26	4.47	4.47	6
27	4.61	4.61	6
28	4.75	4.75	6
29	4.89	4.89	6
30	5.03	5.03	6
31	5.17	5.17	6
32	5.31	5.31	6
33	5.45	5.45	6
34	5.59	5.59	6
35	5.72	5.72	6
36	5.86	5.86	6

Table 5: Demand, order, and wholesaler warehouse by the exponential smoothing method.

Period	Demand	Order	Warehouse
1	2	8	6
2	3.64	0	2.36
3	2.44	6.08	6
4	1.63	0	4.37
5	1.09	0	3.27
6	2.47	5.2	6
7	1.66	0	4.34
8	1.11	0	3.23
9	2.53	5.3	6
10	1.7	0	4.3
11	2.56	4.26	6
12	1.72	0	4.28
13	2.76	4.47	6
14	1.85	0	4.15
15	3.03	4.88	6
16	2.03	0	3.97
17	3.34	5.37	6
18	2.24	0	3.76
19	3.66	5.9	6
20	2.45	0	3.55
21	3.99	6.44	6
22	2.67	0	3.33
23	4.32	7	6
24	4.23	4.23	6
25	4.22	4.22	6
26	4.25	4.25	6
27	4.32	4.32	6
28	4.42	4.42	6
29	4.53	4.53	6
30	4.64	4.64	6
31	4.77	4.77	6
32	4.9	4.9	6
33	5.03	5.03	6
34	5.17	5.17	6
35	5.31	5.31	6
36	5.44	5.44	6

the wholesaler demand was forecasted. Table 5 shows the quantities of demand and wholesaler order and the amount of inventory in different periods.

The logic of two-bin (6 and 2) wholesaler like the other levels is that a quantity is ordered at the beginning of the period that in addition to meeting the demand at the beginning of the period, it maximizes the amount of inventory at the beginning of the period. In other words, it fills larger and smaller bins and the forecasted demand quantities, the larger bin is used first and as soon as the larger bin is finished, it is the reorder point, a new order is issued, and the smaller bin is used until the new order arrives and fills both bins.

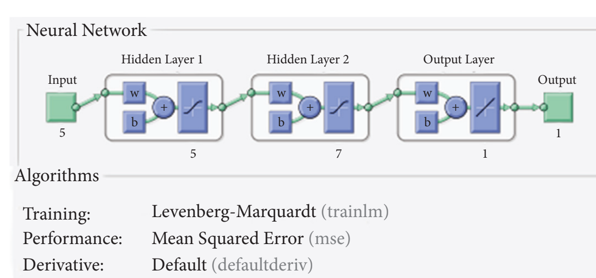

Figure 3: Neural network.

3.5. Forecasting Manufacturer Level Demand Using Neural Network. Manufacturer demand was forecasted using the multilayer perceptron neural network method. A multilayer perceptron network with hidden two-layer specifications was used to model the data. Using coding in MATLAB software, time series data were arranged according to intelligent guesses and determined optimal time delays and interruptions. Levenberg-Marquardt was used to train the neural network because it is the fastest method of progressive neural networks with medium to high size up to several hundred weights, and using the trial and error method, different values were considered for middle layer neurons. Finally, the number of middle layer neurons was selected based on the outputs. The activity functions tansig

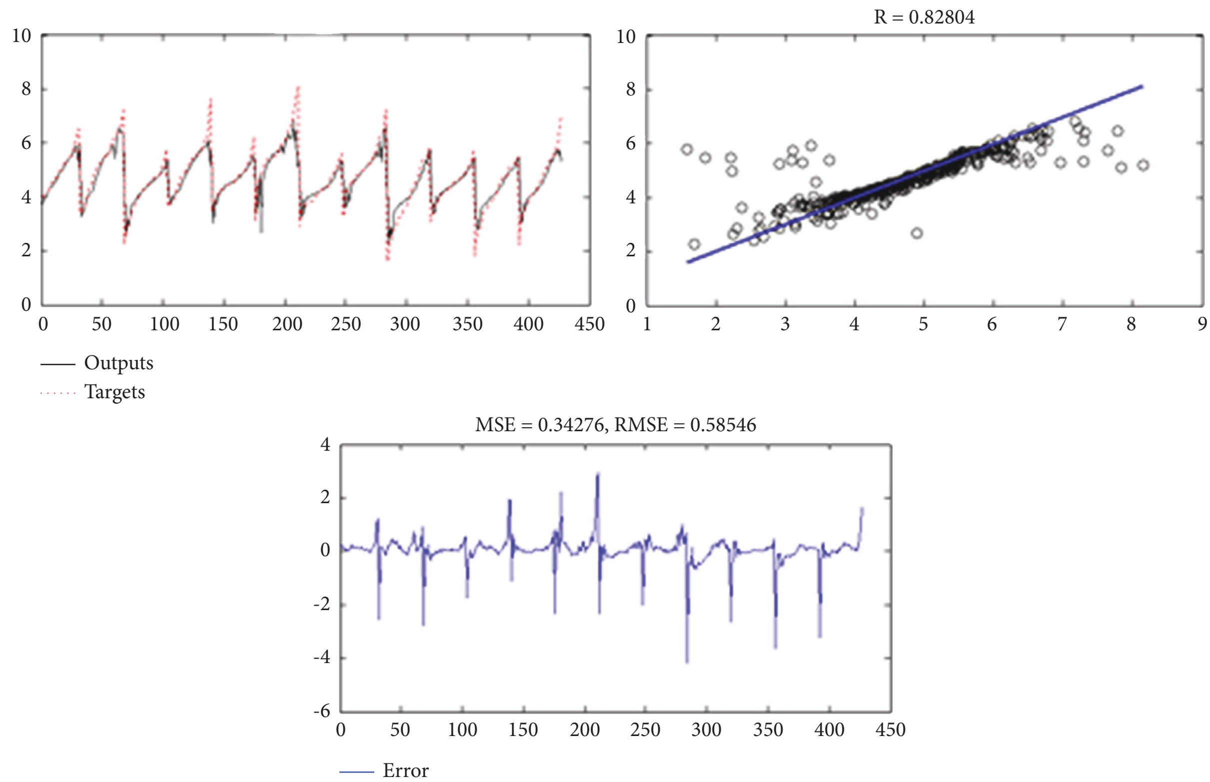

Figure 4: Diagram of forecasted demand and expected demand of the neural network.

and purelin were also written as sigmoid functions for output. After giving the historical input data to MATLAB software, using the given functions and time delays, MATLAB software receives 60% of the data for training, 20% for validation during training, and the remaining 20% for the test. Finally, it compares the forecasted output with the expected output with the mean squared error index. Figure 3 shows the neural network.

As shown in Figure 4, left-top, the red dots are the expected demand values and the black dots are the forecasted demand of the neural network. And the top-right diagram shows the dispersion of the points. The bottom diagram shows the MSE error value, which indicates good forecasting of the neural network with a slight error. Table 6 shows the demand by the neural network method and order by two-bin method and the manufacturer warehouse quantities.

3.6. Forecasting the Supplier Level Demand Using the Moving Average Method. Then, using the manufacturer's order quantity, the supplier demand was forecasted by the moving average. Note that the amount of inventory at the beginning of the period is considered zero. As can be seen from the data in Table 7, the order amount of the first period is equal to the demand of the first period plus the maximum amount of warehouse volume (larger bin) and for the second period, because we have no demand, no order is placed and the inventory remains the same. And for the third period, because the amount of demand is more than the amount of inventory, the order is placed as much as the amount of demand. The amount of demand and orders continues in the same way until the sixth period, and the amount of demand is the size that the inventory does not become less than 2 units (smaller bin) so no order is placed. This process of two-bin ordering system continues until the last period.

4. Results

4.1. Calculating the Bullwhip Effect. For this purpose, firstly we define the predetermined parameter for using regression prediction in Minitab and the neural network in MATLAB as follows:

(i) Variance of manufacturer order = 13.34

(ii) Variance of retailer demand = 2.17

(iii) Bullwhip effect value = 6.14

Using regression prediction in Minitab and neural network prediction in MATLAB, the logic of different scenarios is written in Excel software and the bullwhip effect for the first 36 random data in 24 scenarios is shown according to Table 8.

4.2. Introducing the Superior Model. Now, taken from the central limit theorem in probability theory, it states that under certain conditions, the mean of a large number of independent random variables, each with a known value and a certain variance, will have an approximately normal distribution. Therefore, this experiment was repeated 50 times

Table 6: Demand, order, and manufacturer warehouse by the neural network method.

Period	Demand	Order	Warehouse
1	4.05	10.05	6
2	2.06	0	3.94
3	5.34	7.4	6
4	2.73	0	3.27
5	3.46	6.19	6
6	1.22	0	4.78
7	3.47	4.69	6
8	2.69	0	3.31
9	1.04	0	2.27
10	3.09	6.82	6
11	0	0	6
12	2.76	0	3.24
13	5.96	8.72	6
14	3.62	0	2.38
15	4.88	8.5	6
16	2.08	0	3.92
17	4.27	6.35	6
18	3.45	0	2.55
19	4.28	7.73	6
20	1.83	0	4.17
21	4.07	5.9	6
22	2.8	0	3.2
23	1.54	4.34	6
24	7.22	7.22	6
25	0	0	6
26	3.74	0	2.26
27	4.78	8.52	6
28	5.25	5.25	6
29	5.03	5.03	6
30	2.96	0	3.04
31	5.67	8.63	6
32	6.38	6.38	6
33	4.77	4.77	6
34	4.9	4.9	6
35	0.07	0	5.93
36	5.17	5.24	6

and the results of the bullwhip effects were obtained in Table 9.

Rest of Table 9. Values of bullwhip effect resulting from the simulation.

Now, the hypothesis is tested whether the mean of bullwhip effect in different forecasting scenarios is significantly different from each other?

$$\begin{cases} H_0\colon \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 \\ = \mu_8 = \ldots\ldots \mu_{22} = \mu_{23} = \mu_{24}. \\ H_1\colon \end{cases} \quad (2)$$

At least two of the means are not equal.

According to Table 10, because the value of $F = 1.22$ is greater than the value of $F_{.05,\ 23,\ 1176}$, the null hypothesis is rejected at the significant level of 5% and it can be claimed that the difference of the means at the level of 5% is significant. Using the one factor analysis of variance in Minitab software, as the results of analysis of variance show, the null hypothesis about the equality of the mean of bullwhip effect

Table 7: Demand and order and supplier warehouse by the moving average method.

Period	Demand	Order	Warehouse
1	10.05	16.05	6
2	0	0	6
3	7.4	7.4	6
4	0	0	6
5	4.36	4.36	6
6	3.4	0	2.6
7	3.4	6.8	6
8	2.72	0	3.28
9	2.72	5.44	6
10	1.17	0	4.83
11	2.88	4.05	6
12	1.71	0	4.29
13	1.71	0	2.59
14	3.89	7.3	6
15	2.18	0	3.82
16	4.31	6.49	6
17	4.31	4.31	6
18	3.71	0	2.29
19	3.71	7.42	6
20	3.52	0	2.48
21	3.52	7.04	6
22	3.41	0	2.59
23	3.41	6.82	6
24	2.56	0	3.44
25	4.37	6.93	6
26	2.89	0	3.11
27	2.89	5.78	6
28	3.94	0	2.07
29	3.44	7.38	6
30	4.7	4.7	6
31	4.7	4.7	6
32	4.73	4.73	6
33	5.01	5.01	6
34	4.95	4.95	6
35	6.17	6.17	6
36	4.01	4.01	6

Table 8: Values of bullwhip effects for different forecasting scenarios.

Scenario	Bullwhip effects
1	6.14
2	2.42
3	4.9
4	2.42
5	4.8
6	3.51
7	6.69
8	2.09
9	3.6
10	2.09
11	11.34
12	0.62
13	6.36
14	8.84
15	7.54
16	6.49
17	4.88
18	5.1
19	2.39
20	1.35
21	4.1
22	7.35
23	1.9
24	1.9

Table 9: Values of bullwhip effect resulting from the simulation.

Period		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	1	6.14	13.34	2.86	10.45	15.21	27.42	18.91	6.08	17.89	3.58	6.3	1.23	3.39	5.58	4.65	3.68	4.05
	2	2.42	15.78	3.65	10.69	16.32	27.85	19.65	6.28	18.56	3.09	6.58	1.88	1.5	4.08	4.9	8.21	5.79
	3	4.9	14.03	2.45	9.08	14.59	26.7	19.98	6.59	17.73	3.96	6.89	2.54	3.61	4.52	5.3	6.83	5.4
	4	2.42	13.05	4.03	11.89	17.57	28.09	20.05	7.51	17.45	4.51	5.11	2.91	5.38	4.88	4.83	7.97	5.66
	5	4.8	14.94	4.056	11.52	17.2	26.63	20.68	7.89	16.96	4.85	5.98	3.55	3.18	4.36	4.27	7.18	3.05
	6	3.51	12.25	4.99	9.63	21.4	27.61	21.21	9.44	16.32	4.12	6.35	3.83	3.73	5.29	7.9	4.52	4.68
	7	6.69	13.19	5.13	11.36	16.06	28.91	22.56	8.76	15.69	3.9	7.12	6.34	4.44	5.39	6.24	8	6.41
	8	2.09	14.05	7.27	12.35	15.63	28.29	22.9	9.41	16.84	4.8	7.44	3.65	3.54	5.7	6.32	5.97	5.58
	9	3.6	14.46	7.4	12.76	20.18	29.11	23.54	8.09	18.26	5.74	6.96	8.07	7.36	8.2	6.47	8.33	8.43
	10	2.09	13.69	5.84	13.25	17.68	29.36	24.02	9.77	15.03	5.6	6.2	4.62	5.27	6.24	6.77	6.54	5.4
	11	2.09	13.69	5.84	13.25	17.68	29.36	24.02	9.77	15.03	5.6	6.2	4.62	5.27	6.24	6.77	6.54	5.4
Predictive	12	0.62	13.75	5.23	12.67	17.43	27.48	23.66	10.07	14.69	6.95	6.3	7.66	3.83	7.59	5.97	5.47	6.87
scenarios	13	6.36	12.28	5.02	13.98	18.15	28.69	22.86	9.62	14.02	5.33	7.21	4.41	5.61	3.6	5.4	6.73	3.93
	14	8.84	13.49	7.12	12.45	15.92	20.94	17.39	8.85	13.95	5.87	7.03	3.91	4.89	6.78	6.09	2.78	4.16
	15	7.54	13.46	6.39	13.23	18.52	27.44	18.04	7.23	12.58	6.32	7.76	1.63	4.19	5.42	3.83	3.72	4.35
	16	6.49	11.79	5.33	12.6	1.084	15.25	19.7	7.85	10.54	6.94	6.92	0.55	3.3	4.69	4.37	2.52	2.78
	17	4.88	7.48	4.78	5.82	14.84	25.25	15.67	8.08	9.34	0.83	6.31	3.57	2.67	4.29	3.7	3.33	4.7
	18	5.1	13.03	7.05	13.12	17.69	26.35	22.54	8.65	14.01	5.22	5.38	2.75	3.71	4.47	3.75	3.9	5.43
	19	2.39	13.21	5.74	11.98	15.28	27	22.03	9.65	14.23	4.89	6.38	3.85	4.11	4.86	4.25	3.73	5.69
	20	1.35	14.04	6.31	11.25	14.87	26.45	23.13	10.21	14.58	5.41	7.51	3.12	3.83	5.15	4.56	4.9	6.2
	21	4.1	15.36	7.14	12.61	13.28	23.1	26.39	10.55	15.33	6.01	6.28	2.85	4.34	5.86	6.48	5.31	7.36
	22	7.35	15.05	7.58	13.12	14.74	26.89	25.46	9.68	16.02	6.21	5.75	4.73	5.13	7.25	6.89	5.46	6.39
	23	1.9	14.45	8.01	12.35	15.02	27.31	24.93	8.7	16.78	6.02	6.64	4.44	5.29	6.66	7.26	7.42	6.43
	24	1.9	14.011	7.81	12.41	15.69	26.06	25.11	9.29	15.8	5.97	7.44	8.35	5.38	7.9	7.05	6.19	7.46

Period		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	1	15.46	12.48	9.23	0.64	2.28	3.61	2.9	8.26	5.24	0.88	3.8	10.46	13.28	8.3	18.08	6.08	1.92
	2	15.63	13.55	9.36	0.75	3.57	4.51	2.58	9.62	5.82	0.76	4.48	11.23	12.56	10.2	17.64	6.18	1.78
	3	14.36	13.48	9.98	4.63	2.65	5.8	1.82	6.08	5.07	0.091	3.71	10.28	12.025	8.97	17.05	6.27	1.62
	4	14.8	12.75	10.45	1.02	3.73	4.21	4.98	7.18	5.72	0.16	4.54	10.36	12.09	8.28	17.45	6.2	148
	5	13.7	15.84	10.1	1.05	4.36	5.26	5.37	7.64	5.64	0.27	7.54	10.94	13.47	8.07	16.96	6.09	1.23
	6	12.53	15.46	14.57	0.52	4.91	2.07	7.81	6.02	5.11	2.58	3.28	10.06	12.6	9.33	16.38	6.11	1.87
	7	15.82	12.08	11.21	4.7	3.88	5.31	10.54	7.33	8.14	4.82	9.58	12.31	14.35	9.34	15.69	6.82	1.34
	8	14.09	13.65	11.87	1.19	4.12	9.05	9.83	8.14	8.94	1.08	6.2	11.64	13.48	9.18	18.09	6.94	1.55
	9	12.43	18.04	12.45	4.59	12.83	10.44	6.04	8.79	8.26	7.12	5.55	17.67	15.48	8.46	19.49	9.28	6.33
	10	13.98	14.54	13.21	1.25	3.88	5.26	7.55	8.53	8.55	1.02	4.38	14.38	13.87	9.17	16.84	11.76	2.08
	11	13.98	14.54	13.21	1.25	3.88	5.26	7.55	8.53	8.55	1.02	4.38	14.38	13.87	9.17	16.84	11.76	2.08
Predictive	12	12.79	14.48	15.37	6.32	2.64	4.051	4.37	7.89	8.46	4.59	3.9	12.37	10.48	9.55	15.03	6.81	2.09
scenarios	13	12.6	11.35	12.02	1.06	4.05	3.65	4.92	7.68	9.24	1.08	5.09	11.08	15	10.25	10.88	6.08	2.31
	14	13.73	12.84	11.65	1.58	5.09	2.89	6.02	5.18	9.08	1.67	4.87	8.39	0.65	10.35	11.37	7.18	2.44
	15	13.43	12.53	10.03	1.49	2.16	3.75	7.05	9.18	9.82	1.09	6.043	12.34	15.2	10.05	14.02	5.04	2.01
	16	0.94	11.49	13.01	1.41	4.88	4.93	6	9.77	3.73	1.22	6.49	8.24	7.99	9.87	6.34	7.31	2.51
	17	13.77	12.53	9.35	1.37	4.67	5.68	4.58	4.28	9.67	1.54	5.62	14.02	13.65	9.02	12.58	7.48	2.81
	18	12.19	10.77	11.58	1.9	3.87	3.26	5.47	10.6	9.28	1.62	6.28	13.84	15.09	10.25	12.57	7.64	1.98
	19	15.31	14.96	12.96	1.81	2.93	2.67	4.87	8.96	8.74	1.08	9.23	13.97	14.37	9.08	13.62	7.8	2.57
	20	14.63	14.47	12.13	1.09	3.54	3.33	5.36	8.27	8.64	3.36	5.95	13.25	15.09	10.37	14.01	7.41	2.66
	21	16.39	15.28	13.05	1.3	4.68	4.28	6.62	9.16	8.91	1.84	4.61	13.2	14.37	9.022	14.23	7.29	2.35
	22	15.61	14.97	13.85	2	4.08	3.65	4.87	9.18	9.23	1.09	6.16	14.05	15.83	10.44	14.58	7.66	3.87
	23	14.84	14.43	14.01	2.05	3.92	4.65	5.28	10.08	9.08	1.14	5.48	13.28	15.6	9.83	15.33	7.09	2.35
	24	15.91	13.72	13.25	2.09	4.8	7.43	4.62	9.64	9.13	1.39	8.62	13.46	14.39	10.8	16.02	8.33	2.77

Table 9: Continued.

Period	35	36	37	38	39	40	41	42	43	44	28	45	46	47	48	49	50
	1	4	1.3	5.67	12.45	3.44	15.36	2.65	8.25	2.33	4.3	2.22	7.45	11.69	6.38	5.05	2.97
	2	3.55	0.6	5.37	10.05	4.68	16.2	3.68	9.13	3.81	4.58	3.03	6.96	11.28	6.04	4.66	2.58
	3	3.46	3.27	5.41	10.76	3.54	15.1	2.94	8.01	3.69	3.88	2.91	6.54	1.89	5.88	4.32	1.88
	4	3.85	1.86	5.88	11.15	4.98	15.97	5.23	9.03	4.01	4.41	3.06	6.03	11.91	6.14	4.78	2.13
	5	3.27	0.054	5.31	11.43	7.67	17.41	6.39	12.47	3.8	7.5	2.11	5.67	1.9	5.77	3.85	1.46
	6	3.64	0.041	9.4	12.21	3.06	14.65	3.02	8.05	2.63	3.66	1.84	6.23	11.45	5.45	3.21	1.22
	7	4.65	5.49	5.89	10.77	9.69	18.92	7.07	12.05	3.65	9.09	1.51	13.47	11.12	4.8	2.51	0.89
	8	4.88	4.18	6.08	8.91	6.32	15.42	5.63	9.62	4.15	6.43	4.69	8.95	13.63	7.96	6.29	3.15
	9	6.33	9.55	8.11	7.65	5.89	14.33	4.12	8.05	0.075	5.86	8.91	10.78	15.81	8.01	4.89	1.79
	10	3.79	0.26	6.34	7.4	4.65	13.28	3.09	7.89	0.093	4.92	4.15	8.11	12.69	6.95	5.01	2.45
	11	3.79	0.26	6.34	7.4	4.65	13.28	3.09	7.89	0.093	4.92	4.15	8.11	12.69	6.95	5.01	2.45
Predictive scenarios	12	3.53	0.44	6.4	9.62	3.76	18.4	3.06	7.63	2.58	9.35	2.89	6.13	11.02	5.3	3.6	2.33
	13	4.68	0.06	6.09	7.25	5.88	11.69	4.89	7.02	0.12	5.69	0.96	5.35	10.21	5.02	3.52	2.69
	14	5.02	0.347	2.39	6.15	4.23	11.21	3.86	6.32	0.456	4.08	1.254	6.39	10.56	5.23	3.93	3.58
	15	5.29	0.64	6.72	5.82	6.08	10.58	5.06	6.91	0.76	6.33	1.01	5.68	9.65	4.71	3.03	2.98
	16	5.3	0.29	4.27	6.39	6.59	9.47	5.39	6.35	0.33	6.79	0.54	4.66	6.38	4.11	3.04	3.05
	17	5.84	0.54	6.54	5.24	5.3	4.72	5.48	6.03	0.57	5.81	0.78	4.87	8.98	4.58	2.46	2.74
	18	5.21	0.42	6.22	5.09	6.35	11.58	4.95	7.41	0.43	6.03	0.63	5.05	8.22	4.12	4.64	2.02
	19	4.92	0.29	6.8	9.66	9.11	14.58	8.64	10.85	2.88	9.13	0.52	4.15	10.02	6.03	3.9	3.99
	20	5.06	0.24	7.11	8.71	5.61	12.96	5.22	7.64	1.85	5.08	0.42	3.69	11.4	6.89	5.16	4.57
	21	5.14	0.36	7.92	9.03	4.12	12.05	4.02	6.93	2.11	4.96	0.68	4.33	12.03	7.24	6.12	5.46
	22	5.22	0.51	7.83	9.55	6.04	14.13	6.11	8.75	3.04	6.25	0.86	5.21	13.02	7.84	6.58	6.02
	23	5.34	0.42	10.84	10.25	5.37	13.57	5.1	7.86	2.55	5.68	1.85	6.11	13.95	8.2	7.14	6.86
	24	5.18	0.59	7.38	10.01	8.51	14.85	7.88	10.23	3.1	8.81	2.13	7.56	13.99	8.61	7.88	7.45

Table 10: Analysis of variance.

Source	DF	Adj-SS	Adj-MS	F-value	P value
Model	23	848.3	36.88	1.22	0.217
Error	1176	35556.0	30.23		
Total	1199	36404.2			

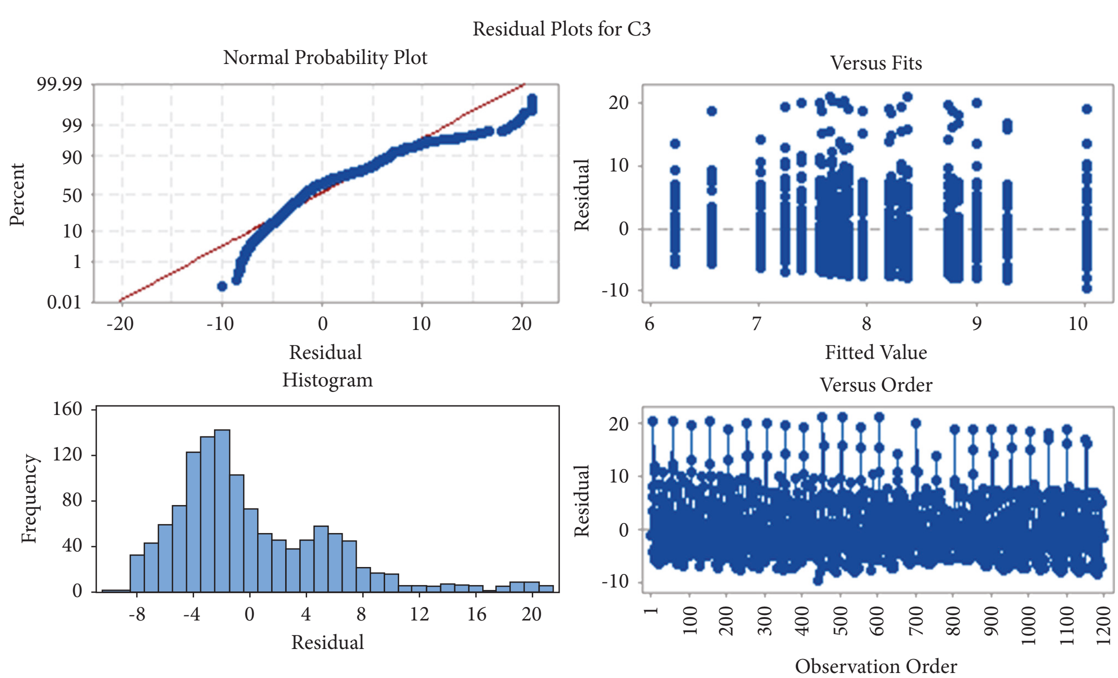

Figure 5: Review of analysis of variance results.

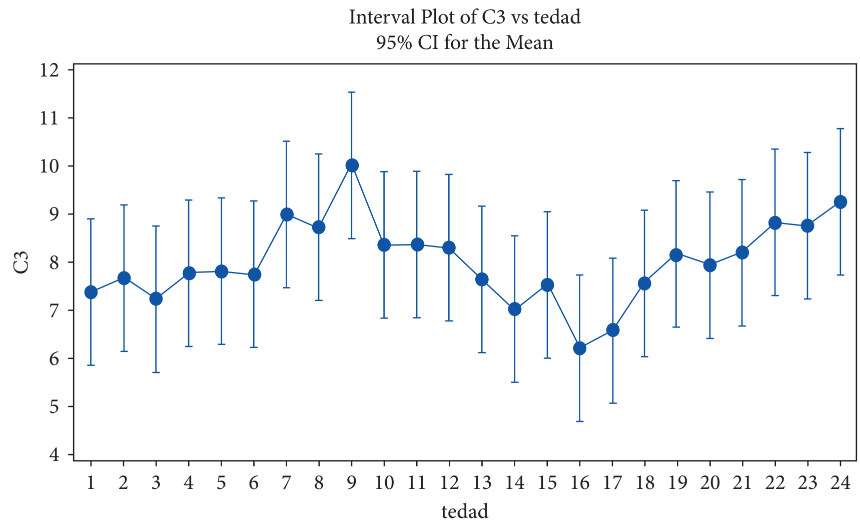

Figure 6: Results of analysis of variance.

in the 24 proposed scenarios is not accepted at 95% confidence level and it can be said that there is a significant difference between different scenarios.

The last issue is related to investigating the accuracy of the hypotheses of the analysis of the variance model. In fact, the method of analysis of variance is based on hypotheses that, if not established, will invalidate the results. The basic hypotheses of analysis of variance are that the model errors of independent random variables have a normal distribution with zero mean and common variance. These hypotheses are investigated in Figure 4. In this figure, the first plot (top left corner) is the normal probability plot of the residuals, which shows that the residuals have a normal distribution with a satisfactory approximation. Normal probability plot is a graphical method for examining the normality of a set of data that plots observations against their cumulative frequency on a sheet called normal probability sheet. If the observations on this sheet are concentrated around a straight line, it indicates that the dataset is normal. As can be seen, the residuals of the analysis of variance are concentrated with a very good percentage around the straight line in the normal probability plot, which is evidence that the residuals are normal. Regarding the equality of variance of errors, the plot of residuals is used in relation to the fitted values (top-right corner). If this plot does not show a specific nonrandom pattern, it indicates that the variance of the errors is equal. As can be seen in the plot, in the present test, this plot shows that the variance of the errors is constant.

The last plot (bottom right corner) also shows the plot of residuals in relation to the time of data collection, which indicates a random pattern. In fact, this plot should not show any specific pattern such as trend and cycle. These methods are fully presented in Montgomery's book.

As shown in Figure 5, the results of analysis of variance, the null hypothesis about equality of the means of bullwhip effect in the 24 proposed scenarios is not accepted at the 95% confidence level and it can be said that there is a significant difference between the different scenarios. Tukey's multiple comparison test was used to detect this difference. Finally, it was proved that Scenario 9 is significantly different from other scenarios, Scenario 16 is also significantly different from other scenarios, and the rest of the forecasting scenarios are not significantly different; therefore, according to the form and findings of the analysis of variance, the best scenario (lowest bullwhip effect) was for Scenario 16. And also, Scenario 9 was introduced as the worst scenario. Significant differences between the mentioned scenarios are shown in Figure 6.

In fact, based on the results of the above analysis, it can be stated that if in the four-level system with the desired hypotheses, retailer, wholesaler, manufacturer, and supplier use neural network, linear regression, smoothing exponential, and moving average, respectively, to forecast their demands, considering impossibility of eliminating errors in the forecast results, the amount of bullwhip effect resulting from this combination of forecasting methods will be less than any other combination, and as a result, this combination will help reduce the bullwhip effect and its negative effects on the supply chain.

4.3. Implication Real Case in Zarbal Company. In the case study, Zarbal Poultry Production Company with four levels of suppliers was considered, and the Zarbal Complex companies in northern Iran are located in the Caspian Sea region and are one of the largest and most experienced chicken meat production companies. In addition to providing part of the domestic and foreign market needs for a day-old broiler chickens, this complex is also active in the field of chicken meat production. Zarbal Company has started its activity in the Iranian poultry industry since 1975, and during this period, by offering superior products, it has always maintained its superiority in terms of quality. In the studied supply chain of Zarbal Company, we consider the community of four Zarbal agencies in Babol City as the

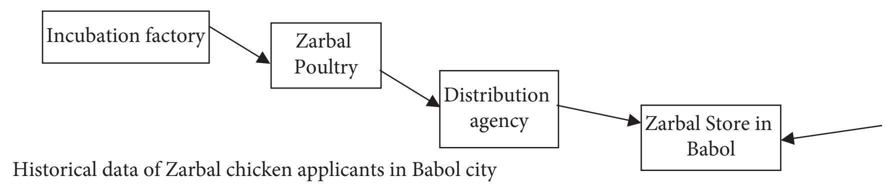

Figure 7: 4-level supply chain of Zarbal Company.

retailer level, the Zarbal exclusive distribution agency as the wholesale level, the Zarbal broiler poultry hall as the manufacturer level, and the Zarbal incubator factory as the supplier level. The two-bin ordering method (300 and 2000) was used for all levels of the supply chain. As the results of analysis of variance showed, the best scenario for forecasting the four-level supply chain, Scenario 16, i.e., the neural network method for the retailer level, the linear regression method for the wholesale level, the moving average method for the manufacturer level, and the exponential smoothing method for the supplier level were introduced, which is as follows for the case study. Figure 7 shows Zarbal Company's 4-level supply chain.

4.3.1. Forecasting Retailer by Neural Network Method in Agencies Other than Babol City. Using historical data of customer demand from the total of four Zarbal distribution centers in Babol City and by the artificial neural network of multilayer perceptron, the demand of Babol retailers was forecasted. The results of neural network forecast are shown in Table 11.

4.3.2. Forecasting Zarbal Company Agency by Regression Method. The null hypothesis of the correlation test indicates the absence of a correlation relationship, and the alternative hypothesis confirms the existence of a correlation relationship. As shown in Figure 8, because p value < 0.05, the null hypothesis is rejected, and the two variables X and Y are correlated. Forecasting was performed using the linear regression method and the following equation. Table 12 shows forecasting Zarbal Company agency by the linear regression method:

$$\begin{cases} H_0: \rho = 0 \\ H_1: \rho \neq 0 \end{cases} \quad (3)$$
$$Y = 1841 + X5.988.$$

4.3.3. Forecasting Zarbal Poultry by Moving Average Method. Zarbal distribution agency was forecasted by the moving average method with $p = 4$. The demand forecast values of Zarbal poultry and orders obtained by the two-bin method are shown in Table 13.

4.3.4. Forecasting Zarbal Company Incubator Factory by Exponential Smoothing Method. Using the order quantity obtained in the previous period at the level of Zarbal poultry and forecasting the demand of the previous period at the level of Zarbal incubation with a coefficient $\alpha = 0.33$, the demand for the next period at the level of Zarbal poultry was forecasted by exponential smoothing method, and the results of which are shown in Table 14.

Table 11: Forecasting the demand of agencies other than Babol city by the neural network method.

Period	Demand	Order
1393/02/06	1882	2000
1393/02/09	1868	1868
1393/02/13	1862	1862
1393/02/15	1856	1856
1393/02/18	1853	1853
1393/02/22	1862	1862
1393/02/25	1856	1856
1393/02/28	1856	1856
1393/02/31	1850	1850
1393/03/04	1864	1864
1393/03/07	1877	1877
1393/03/10	1882	1882
1393/03/13	1894	1894
1393/03/17	1807	1907
1393/03/21	1917	1917
1393/03/24	1927	1927
1393/03/27	1931	1931
1393/03/31	1942	1942
1393/04/04	1957	1957
1393/04/09	1973	1973
1393/04/14	1983	1983
1393/04/17	1995	1995
1393/04/21	2005	2005
1393/04/25	2006	2006
1393/04/29	2015	2015
1393/05/02	2019	2019
1393/05/06	2026	2026
1393/05/12	2020	2020
1393/05/14	2025	2025
1393/05/16	2027	2027
1393/05/18	2031	2031
1393/05/20	2031	2031
1393/05/22	2031	2031
1393/05/25	2031	2031
1393/05/29	2031	2031
1393/06/03	2040	2040

Finally, the value of bullwhip effect for these levels of Zarbal Company chain using the combination of forecasting methods presented in Scenario 16 is 3.892. This is while the value of bullwhip effect for this level of the chain with traditional and mental methods was 8.428. And this super-good growth is the combined forecasting method of the proposed model.

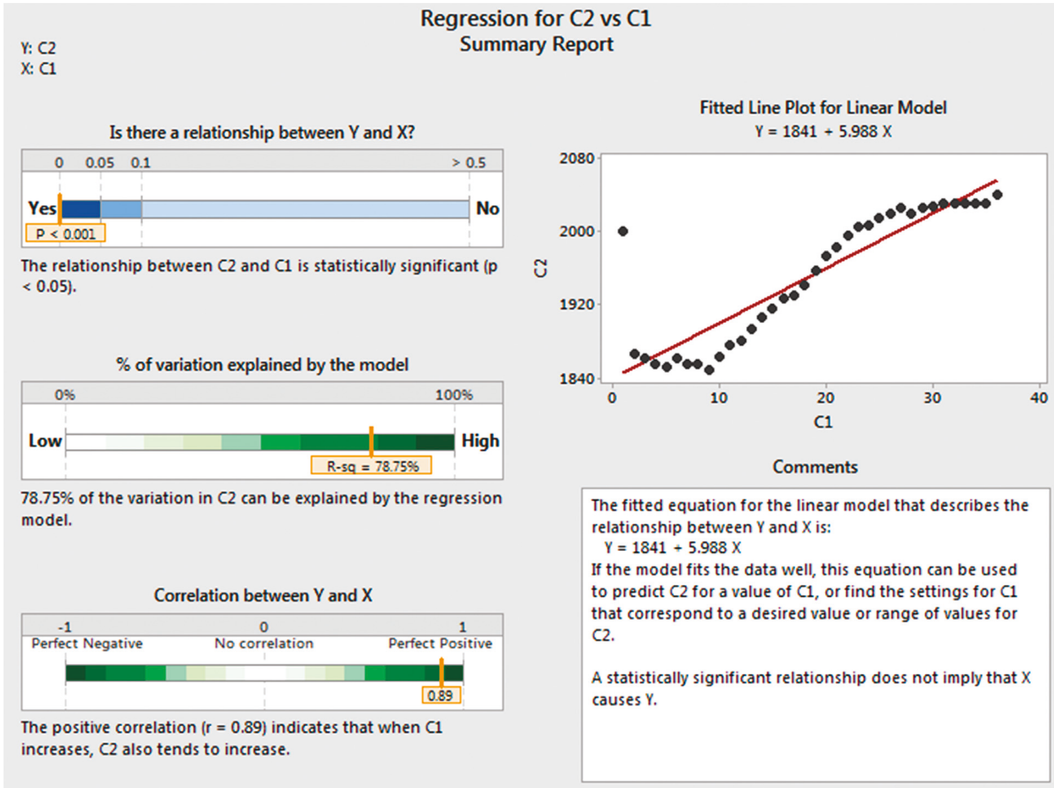

Figure 8: Diagram of correlation of Zarbal distribution agency demand.

Table 12: Forecasting Zarbal Company agency by the linear regression method.

Period	Demand	Order
1393/02/06	1847	3847
1393/02/09	1853	1853
1393/02/13	1859	1859
1393/02/15	1865	1865
1393/02/18	1871	1871
1393/02/22	1877	1877
1393/02/25	1883	1883
1393/02/28	1889	1889
1393/02/31	1894	1894
1393/03/04	1900	1900
1393/03/07	1906	1906
1393/03/10	1912	1912
1393/03/13	1918	1918
1393/03/17	1924	1924
1393/03/21	1930	1930
1393/03/24	1936	1936
1393/03/27	1942	1942
1393/03/31	1948	1948
1393/04/04	1954	1954
1393/04/09	1960	1960
1393/04/14	1966	1966
1393/04/17	1972	1972
1393/04/21	1978	1978
1393/04/25	1984	1984
1393/04/29	1990	1990
1393/05/02	1996	1996
1393/05/06	2002	2002
1393/05/12	2008	2008

Table 12: Continued.

Period	Demand	Order
1393/05/14	2014	2014
1393/05/16	2020	2020
1393/05/18	2026	2026
1393/05/20	2032	2032
1393/05/22	2038	2038
1393/05/25	2044	2044
1393/05/29	2050	2050
1393/06/03	2056	2056

Table 13: Forecasting Zarbal Company with the moving average method.

Period	Demand	Order
1393/02/06	1870	1870
1393/02/09	1853	1853
1393/02/13	1859	1859
1393/02/15	1865	1865
1393/02/18	2356	2356
1393/02/22	1862	1862
1393/02/25	1868	1868
1393/02/28	1874	1874
1393/02/31	1880	1880
1393/03/04	1886	1886
1393/03/07	1892	1892
1393/03/10	1897	1897
1393/03/13	1903	1903
1393/03/17	1909	1909
1393/03/21	1915	1915
1393/03/24	1921	1921
1393/03/27	1927	1927
1393/03/31	1933	1933
1393/04/04	1939	1939
1393/04/09	1945	1945
1393/04/14	1951	1951
1393/04/17	1957	1957
1393/04/21	1963	1963
1393/04/25	1969	1969
1393/04/29	1975	1975
1393/05/02	1981	1981
1393/05/06	1987	1987
1393/05/12	1993	1993
1393/05/14	1999	1999
1393/05/16	2005	2005
1393/05/18	2011	2011
1393/05/20	2017	2017
1393/05/22	2023	2023
1393/05/25	2029	2029
1393/05/29	2035	2035
1393/06/03	2041	2041

Table 14: Forecasting Zarbal incubator factory by the exponential smoothing method.

Period	Demand	Order
1393/02/06	1700	1400
1393/02/09	2416	2416
1393/02/13	2230	2230
1393/02/15	2108	2108
1393/02/18	2027	2027
1393/02/22	2136	2136
1393/02/25	2045	2045
1393/02/28	1987	1987
1393/02/31	1949	1949
1393/03/04	1926	1926
1393/03/07	1913	1913
1393/03/10	1906	1906
1393/03/13	1903	1903
1393/03/17	1903	1903
1393/03/21	1905	1905
1393/03/24	1909	1909
1393/03/27	1913	1913
1393/03/31	1918	1918
1393/04/04	1923	1923
1393/04/09	1928	1928
1393/04/14	1934	1934
1393/04/17	1940	1940
1393/04/21	1946	1946
1393/04/25	1951	1951
1393/04/29	1957	1957
1393/05/02	1963	1963
1393/05/06	1969	1969
1393/05/12	1975	1975
1393/05/14	1981	1981
1393/05/16	1987	1987
1393/05/18	1993	1993
1393/05/20	1999	1999
1393/05/22	2005	2005
1393/05/25	2011	2011
1393/05/29	2017	2017
1393/06/03	2023	2023

4.4. Discussion and Comparison. Many researchers have studied the effect of forecasting methods on bullwhip, which was mentioned in the literature review. However, Najafi and Zanjirani Farahani [28] compared the effect of various forecasting methods such as moving average, exponential smoothing, and regression in creating or intensifying the bullwhip effect in a four-level supply chain on bullwhip effect and by three demand models, used the pairwise comparison test to analyze his results. Esmaili et al. [29] also investigated the two methods of moving average and exponential smoothing on eight demand models in a two-level chain. In analyzing their results, they used the pairwise comparison of means. Accordingly, the method based on designing experiments and analysis of variance used in the present study can be considered as a distinct aspect of it from previous studies, which gives more stability to the results. In other study, Razavi Hajiagha et al. [30] investigated the effect of combined application of forecasting methods on bullwhip in three-level supply chains with a simulation approach and the assumption of dissimilarity of forecasting methods in a combined scenario and they analyzed the results using analysis of variance. Kohansal used three smoothing methods of Holt-Winters, ARIMA, and artificial network to forecast the egg price. Based on the results, the forecast of the neural network method is closer to reality. According to the above comparison, there is no study that can reduce the effect of bullwhip on the supply chain using statistical-mathematical analysis simultaneously. In general, only mathematical prediction tools have been used. For this purpose to fill gap in this research, forecast for retail demand using regression model; wholesale demand using exponential smoothing model; manufacture demand using neural network, and supplier demand using moving average method have been done.

5. Managerial Insights and Practical Implications

By moving from the bottom of the chain to the top of the supply chain, small changes at the bottom cause large changes at the top. These changes will cause large fluctuations in the supply chain because it has been shown that the sources of change in the supply chain are very wide. If these changes are transferred to the higher levels of the supply chain with a time delay, they will delay the production and transportation of goods to the lower categories and will have the effect of a bullwhip.

6. Conclusion

In this study, we explored the demand forecasting in supply chain, a four-level chain of retailers, wholesalers, manufacturers, and suppliers. Each level of the chain forecasted demand by moving average method, exponential smoothing, multilayer perceptron artificial neural network, and regression. Also, we provide a hybrid model based on statistics and mathematics to reduce the effect of bullwhip. For this purpose, main contrition of the paper is predicting demand in a four-level supply chain with retailers, wholesalers, manufacturers, and supplier elements. Also, we provide a hybrid model based on statistics and mathematics to reduce the effect of bullwhip. Therefore, in this study, using four methods that most researchers used to forecast, including moving average, exponential smoothing, linear regression, and multilayer perceptron neural network, the demand value of the four-level supply chain was forecasted with the assumption that none of the forecasting scenarios use any similar method. For this purpose, main results of the paper are as follows:

(i) Forecast retail demand using the regression model.

(ii) Forecast wholesale demand using the exponential smoothing model.

(iii) Forecast manufacturer demand using the neural network.

(iv) Forecast supplier demand using the moving average method.

Also, the quantities of orders were obtained using the two-bin method; then, the effect of the bull whip was calculated by calculating the variance of supplier orders to the variance of retailer demand. And by the analysis of variance and pairwise comparison test, the best combined scenario with the least bullwhip effect in the four-level supply chain was introduced. In the case study of Zarbal Company, with the best bullwhip effect, Scenario 16, the demand of Zarbal chicken stores (retailer) by the neural network method, Zarbal chicken distributors (wholesaler) by the linear regression method, Zarbal poultry (manufacturer) by the moving average method, and the incubator factory (supplier) by the exponential smoothing method forecasted, which reduced the bullwhip effect. Suggestions for the development of this article are as follows. Considering the uncertainty in the calculations, we develop a simulation model and introduce a hybrid approach based on simulation and statistics.

Data Availability

All data are given in the article file.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Customer Churn Modeling via the Grey Wolf Optimizer and Ensemble Neural Networks

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The customer churn is one of the key challenges for enterprises, and market saturation and increased competition to maintain business position has caused companies to make all attempts to identify customers who are likely to leave and end their relationship with a company in a particular period to become the customer of another company. In recent years, many methods have been developed including data mining for predicting the customer churn and manners that customers are likely to behave in the future and therefore, taking action early to prevent their leaving. This study proposes a hybrid system based on fuzzy entropy criterion selection algorithm with similar classifiers, grey wolf optimization algorithm, and artificial neural network to predict the customer churn of those companies that suffer losses from losing customers over time. The research results are evaluated by other methods in the criteria of accuracy, recall, precision, and F_measure, and it is declared that the proposed method is superior over other methods.

1. Introduction

The expansion of business and commerce environment and the advent of various communication platforms such as the Internet has made it an easy experience for customers to be informed of similar services and products offered by different companies in the shortest time. Accordingly, in the event of dissatisfaction, customers can switch to another company, which leads to the rise of customer churn of the prior company [1]. Managers in all types and sizes of organizations in recent years with the help of researchers in diverse fields have used different methods to predict and prevent the loss of their customers. One of the efficient methods that have been considered by researchers beside the expansion of artificial intelligence to predict customer churn is the use of data mining methods including artificial neural network methods, decision tree, logistic regression, support vector machine, and random forest [2].

Moreover, Amin et al. [3] showed that if companies can decrease the amount of customer losses by almost 5%, they can increase profits by 25 to 95%. Some of the most prominent problems that customer losses cause for companies are as follows [4].

(i) Financial losses due to the decline of profits from lost customers, as well as the high cost of new customers' absorption.
(ii) Negative effects on current customers and these may cause them to leave the company.
(iii) Providing the opportunity for competing companies to expand their business by attracting those customers.

Thus, the main objective of the present study is to provide a hybrid method for predicting customer churn with high accuracy based on fuzzy entropy measures with similarity classifier, grey wolf optimizer (gwo), and ensemble neural network. Thus, the main questions of this research are as follows:

(i) Is it possible to provide a hybrid method based on fuzzy entropy measures with similarity classifier, grey wolf optimizer, and ensemble neural network, which can predict customer churn with high accuracy?

(ii) To what extent can the use of ensemble neural networks instead of conventional neural networks be effective in improving customer predictability?

In the following, in Section 2, the research background is examined. Section 3 describes the research method. In Section 4, the results are numbered and analyzed, and finally in Section 5 conclusions are made.

2. Literature Review

In recent years, the issue of predicting and preventing customer losses has become very important for organizations, and researchers have used various methods to develop systems. De Bock and Van den Poel [4] reviewed the application and evaluation of the performance of the hybrid classification method based on the generalized additive model in predicting customer churn. To compare and evaluate the efficiency of the hybrid model based on the generalized additive model, the bagging method, random forest algorithm, random sub-space algorithm, and logistic regression method have been used. Chen et al. [5] proposed a new framework for predicting customer churn using the longitudinal data method. They applied support vector machine methods, boosting, neural networks, decision tree, random forest, logistic regression, and proportional hazard model. The dataset used in their study was from a food and telecommunication company. Sharma et al. [6] proposed a method for predicting customer churn using multilayer perceptron neural networks. The dataset used was from a U.S. mobile telecommunication company. The results indicate that neural network can be used as an efficient method in predicting customer churn, and telecommunication companies can use the proposed method for this aim. Coussement and De Bock [7] presented a comparison between single data mining methods and hybrid methods, which are actually a combination of several data mining methods in predicting customer churn. They compared methods such as generalized additive model, random forest algorithm, decision tree, and the results showed the superiority of hybrid methods. The data used in this study is related to 3729 customers of the online betting company. Tang et al. [8] examined the impact of using derived behavior information on customer attrition in the financial services industry. They used orthogonal polynomial analysis method to obtain the derived information. Proportional hazards model has also been used to predict customer attrition. The dataset used in this article is related to the customers of a bank. Keramati et al. [9] proposed a hybrid system based on feature selection methods, artificial neural networks, support vector machine, decision tree, and K-nearest neighbor to predict customer churn. The data about 3150 customers of one of the telephone operators in Iran that have been collected during 12 months Moeyersoms and Martens [10] used highly correlated customer information features to predict customer churn. In this study, the decision tree classification methods, support vector machine, and logistic regression methods are used to predict customer losses on customer datasets of different energy industries. Coussement et al. [11] evaluated the efficiency of data preprocessing methods on the efficiency of customer churn prediction methods. In this study, decision tree and logistic regression methods, Bayesian networks, support vector machine, and another method called random boosting gradient and bagging have been used to predict customer churn. The data used is related to 30104 customers of a European telecommunication company. Yu et al. [12] proposed a hybrid method based on error propagation neural networks and a particle swarm optimization algorithm to predict customer churn. The reason for using the particle swarm optimization algorithm is to obtain neural network parameters such as weights and bias values so that the data can be well trained in the neural network. The results of this study indicate that the neural network with particle swarm optimization training algorithm offers better performance in predicting customer churn than the neural network method with error replication algorithm.

Salvi et al. [13]; in a study examined the LSTM neural network and used it to predict the future trend of Brent oil prices based on the previous price of Brent oil. In this study, 4 types of errors have been calculated to check the accuracy of the model and errors. The mean absolute error (MAE) and Root Mean Square Error (RMSE) were 1.1962 and 1.9164, respectively.

Moitra et al. [14] attempted to use short-term memory neural network instead of convolutional neural network to predict crude oil price. Results were promising and showed more accurate forecasts for crude oil prices in the coming days, and a hybrid model was presented for forecasting crude oil price that used sophisticated network analysis and LSTM algorithms. The research results showed that the model is more accurate and has more robustness and reliability. Jafarzadeh Ghoushchi et al. [15]; provided an extended approach to the diagnosis of tumour location in breast cancer using deep learning. This study develops a new machine learning approach based on modified deep learning (DL) to diagnose the tumour location in breast cancer. In this study, the data obtained from the databases (BCDRD01) are developed and resized and divided into datasets. A simple architecture is used for the first group of experiments, one of which utilizes a weighted function to counter the class imbalance. The results indicate that convolutional neural networks (CNNs) are an appropriate option for the separation of breast cancer lesions.

Raju et al. [16]; have developed an approach to forecasting demand in the steel industry using group learning. This study aims to introduce a robust framework for

Table 1: Paper classification.

Author	Year of publication	Goal	Model
Raju et al.	2022	Developed an approach to forecasting demand in the steel industry	Regression ensemble framework
Jafarzadeh et al.	2021	Provided an extended approach to the diagnosis of tumour	New machine learning approach
Jnr et al.	2021	Hybrid ensemble intelligent model for electricity demand forecasting	Swarm intelligence and artificial neural network
Moitra et al.	2020	Predict crude oil price	Short-term memory neural network
Salvi et al.	2019	Predict the future trend of brent oil prices	LSTM neural network
Yu et al.	2018	Proposed a hybrid method to predict customer churn	Neural networks and a particle swarm optimization algorithm

forecasting demand, including data preprocessing, data transformation and standardization, feature selection, cross-validation, and regression ensemble framework. In order to maximize the determination coefficient () value and reduce the root-mean-square error (RMSE), hyperparameters are set using the grid search method. Using a steel industry dataset, all tests are carried out under identical experimental conditions. In this context, STACK1 (ELM + GBR + XGBR-SVR) and STACK2 (ELM + GBR + XGBR-LASSO) models provided better performance than other models. As it improves the performance of models and reduces the risk of decision-making, the ensemble method can be used to forecast the demand in a steel industry one month ahead.

Ofori-Ntow et al. [17], have developed an hybrid ensemble intelligent model based on wavelet transform, swarm intelligence, and artificial neural network for electricity demand forecasting. In this study, a three-level hybrid ensemble short-term load forecasting method consisting of discrete wavelet transform (DWT), particle swarm optimization (PSO), and radial basis function neural network (RBFNN) is proposed. The DWT is applied to decompose the data to get a well-behaved requisite series for forecasting since the data becomes stable before using PSO. The statistical analysis revealed that the proposed method performed better based on MAPE, MAD, and RMSE emphasizing its great potential. Table 1 shows the literature review.

3. Methodology

In this research, a hybrid system based on fuzzy entropy measures with similarity classifier, grey wolf optimizer and ensemble neural networks to predict customer churn. As can be seen from the diagram of the proposed system in Figure 1, the proposed system consists of five main steps, which we will briefly review in detail below.

3.1. Collect Customer Data and Pre-Process the Data. In the proposed method, the neural network machine learning tool is applied to predict the customer churn in the customer's classification stage. In other words, the neural network must learn the data of previous lost and non-lost customers of the company, which has been collected by the company during a certain period of time. According to patterns and relationships between customers, the customer churn and their loyalty can be predicted. In other words, it can be predicted which customers would probably leave the company in the future and which customers would remain loyal.

After collecting the customer data, preprocessing is performed on the data to prepare the data. The preprocessing step involves several different operations performed to prepare the data. One of the steps taken is to convert text or character data or string to numeric data. Normalization is another method of data preprocessing which is performed on data before it is used by machine learning algorithms to make predictions. Its purpose is to solve problems caused by large differences in different data properties in some computational processes. That is to say, the aim of normalizing the data is to prevent the dominance of numbers in the larger range to numbers in the smaller range [18]. Another method of preprocessing data is to deal with missing data. Samples of customer data containing missing data are removed from the dataset, by reason of not interfering with the neural network predictor modeling process by this kind of data.

3.2. Selection of Optimal Features and Removal of Redundant and Additional Features. The feature selection process in the system is performed using the fuzzy entropy measures with similarity classifier. This feature selection algorithm was proposed by Luukka [19]; in which the fuzzy entropy criterion is used to select the optimal features and remove the redundant features of the data. At this stage, the customer dataset is given to this algorithm, which specifies some properties that can be removed from the data in its output.

Obtain optimal structures using the grey wolf algorithm: The grey wolf algorithm is used to predict the customer churn to obtain two optimal structures for each of the ensemble neural networks. That is, the grey wolf algorithm starts at this stage and during an optimization process identifies two suitable structures or architectures, namely the number of layers and the number of neurons in each layer. One of the most important issues is how to encode the search agents in the grey wolf optimization algorithm.

The grey wolf algorithm proposed by Mirjalili [20] is a continuous algorithm to solve continuous problems, while the problem of obtaining the appropriate structure for the

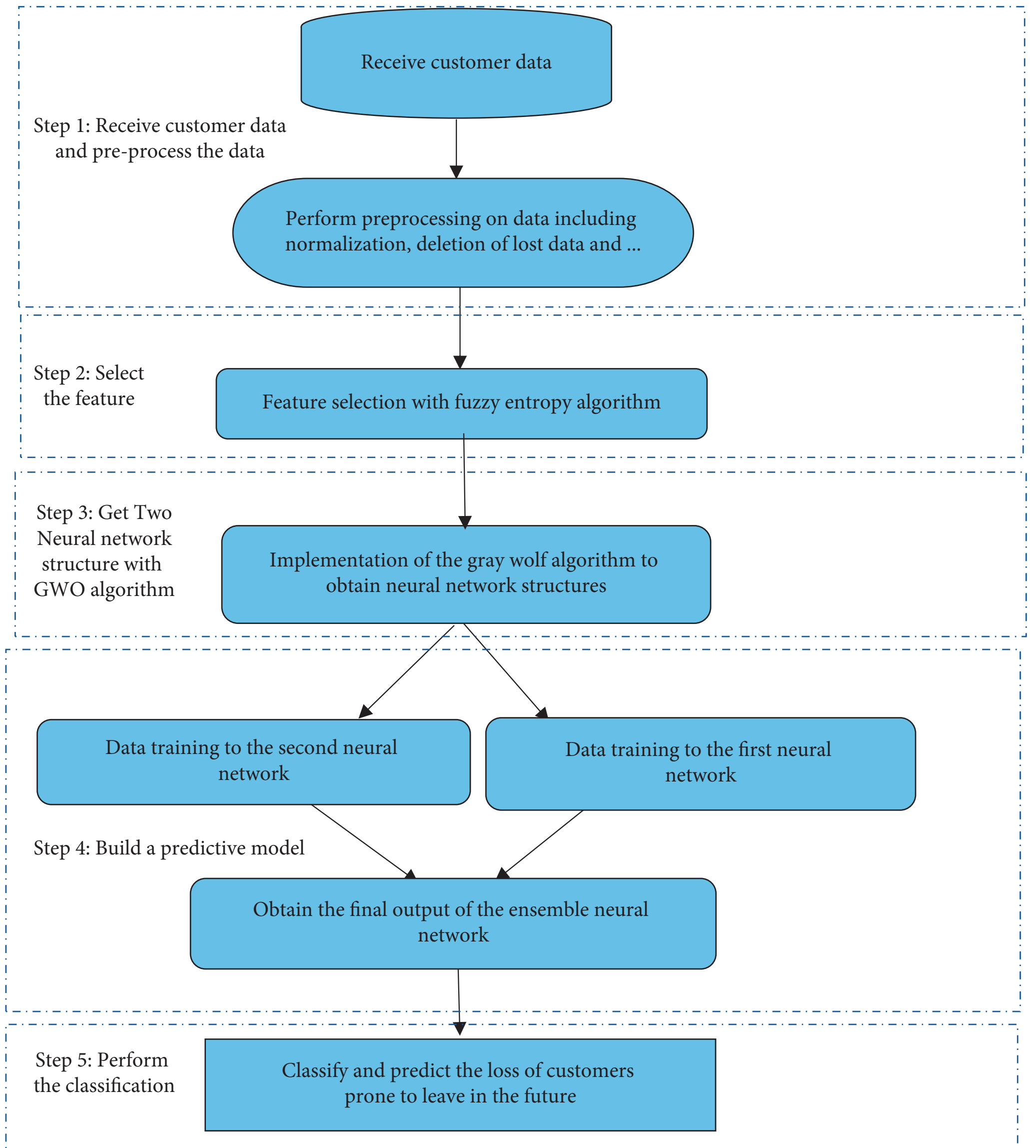

Figure 1: Diagram of the proposed system to predict customer churn.

neural network is a discrete problem. The solution must be a multi-element array with discrete numbers whose number represents the number of layers of the neural network and the value of each cell of the array represents the number of neurons in each layer. Figure 2 presents the solution of the grey wolf algorithm as an array.

On the basis of Figure 2, the array, which consists of four elements, a neural network should be created that consists of four layers in the hidden layer, so that there are 10 neurons in the first layer of this neural network, 20 neurons in the second layer, 8 neurons in the third layer, and 12 neurons in the fourth. Another noteworthy point of this type of encoding is that if the value of one of the cells in the array is 0, that cell should be removed from the array; thus, the number of neural network layers will be reduces.

However, the grey wolf algorithm is a continuous algorithm, and when the search agents are initialized at the beginning of the optimization process, the values of each search agent will be continuous or decimal numbers. Therefore, because the problem of selecting the optimal structures for the artificial neural network is a discrete problem, so after each iteration of the algorithm and obtaining the best solution by the problem search agents, the resulting solution, which is continuous, must be discretized using the mapping function. For this reason, a mapping function is used as (1)

10	20	8	12

Figure 2: A hypothetical structure for the neural network.

$$\vec{X}(t)_{i,j} = \left(100 \times \vec{X}(t)_{i,j}\right) \bmod (h_n). \quad (1)$$

In the (1), $\overrightarrow{X}(t)_{i,j}$ represents the j^{th} component of the i^{th} problem search factor in the t^{th} iteration of the grey wolf algorithm. In other words, $\overrightarrow{X}(t)_{i,j}$ represents the j^{th} element of the i^{th} grey wolf. The mod variable is a function for calculating the residual value, and the reason for using this function is to limit the maximum number of neurons in the range 0 to $h_n - 1$. The h_n is the maximum value for the number of hidden layer neurons. Applying this function to any of the problem factors or any of the grey wolves that have continuous solutions will result in discrete solutions. For example, supposing that the value of the first element of one of the solutions to the problem is 0.15 and h_n is equal to 21, the value 15 is obtained.

Another important point about this step of the method is the evaluation function of the search agents in the grey wolf algorithm. That is, in each iteration of the grey wolf algorithm, it is an essential to have a search factor evaluation function to determine which search agent received the best solution. Accordingly, an evaluation function is used to indicate the accuracy of the system for validation data and training data. That is to say, in evaluating each of the population vectors that represent a structure for the neural network, the training data is trained into a neural network with a constructed structure, and after the training process, the accuracy of the neural network prediction is calculated for validation data. Each search engine that maximizes the value of the following relationship is selected as the best member of the population. Equation (2) shows the population members evaluation function.

$$\text{fitness} = 0.7 \times V\_\text{ACC} + 0.3 \times T\_\text{ACC}. \quad (2)$$

In (2), the variables V_ACC and T_ACC indicate the accuracy of forecasting or classifying for the sample in validation and training datasets, respectively. It shows weighted means presenting the accuracy of recognition for validation data and training, so that the importance of accuracy of recognition of validation data is more than the training data.

In this step, two optimal structures must be obtained, so the first solution or the best structure is obtained by alpha wolf, which is the best search agent, and the second solution, or the second best structure is obtained by beta wolf, which represents the second best search engine.

3.3. Building Predictive Model with Ensemble Neural Network. One of the most powerful and famous machine learning tools, namely artificial neural network, has been used to build a model for predicting customer churn. In the proposed system, instead of using a neural network, two neural networks were used to predict the loss of customers with high accuracy by combining the solutions of these two neural networks.

Therefore, at this stage, two multilayer feed neural networks, namely a feed neural network with a solution obtained by alpha wolf and a feed neural network with a solution obtained by beta wolf, were created. Then the dataset was trained to the neural networks with new features obtained from the feature selection stage, and finally the final solution of the predictive model was calculated using (3), which is a weighted average.

$$\text{Output} = 0.5 \times \text{net}\,1 + 0.5 \times \text{net}\,2. \quad (3)$$

In (3), net 1 and net 2 are the outputs of the first neural networks, i.e., the neural network made with the alpha wolf solution, and the second neural network, the neural network made with the solution obtained by the beta wolf, respectively. Output also represents the final solution of the neural network, which is obtained by combining the solutions of two neural networks with the same weighted average.

3.4. Classify and Predict the Customer Churn. After building the classification model, the proposed system is ready to predict the customer churn. Therefore, assuming providing a set of data about current customers of a company, the proposed system can classify and predict customers, who are likely to leave the company in the future. Once customers are identified as prone to leave, managers of organizations and companies can prevent the loss of their customers by taking preventive measures in accordance with the policies of their company.

3.5. Criteria for Evaluating the Proposed Method. Predicting customer churn means classifying and categorizing customers into two classes or classes of customers prone to loss as well as customers loyal to the organization. There are various methods for evaluating the efficiency and performance of classification systems, among which criteria such as accuracy, recall, precision, F-measure, and area under curve can be referred. To calculate these classification criteria, a matrix called the configuration matrix should be applied, which represents the performance of classification systems in data classification. Figure 3 shows the configuration matrix for two-class problems.

As shown in Figure 3, the performance of classification systems in data classification using this matrix and with criteria called true positive (TP), true negative (TN), false positive (FP), false negative (FN) is displayed.

(i) True Positive (TP): Equivalent to the percentage of members of a class such as X that the classifier system correctly classifies as a member of Class X.

(ii) True Negative (TN): Equivalent to the percentage of members of another class, such as Y, whose non-belonging to class X is properly classified.

(iii) False Positive (FP): Equals the percentage of members of another class, such as Y, who are incorrectly classified as members of Class X.

(iv) False Negative (FN): Equals a percentage of the number of members in class X who are incorrectly classified as members of another class, such as Y.

Using the abovementioned criteria, which indicate the performance of classification methods, the performance of classification system can be calculated.

		Ground truth		
		+	−	
Predicted	+	True positive (TP)	False positive (FN)	Precision = TP / (TP + FP)
	−	False negative (FN)	True negative (TP)	
		Recall = TP / (TP + FN)		Accuracy = (TP + TN) / (TP + FP + TN + FN)

Figure 3: Confusion matrix and performance criteria of classification methods.

(i) Accuracy: One of the most famous and oldest evaluation criteria of classification systems is the classification accuracy criterion and it is the ratio of all items that are correctly classified. The accuracy of the classification is calculated as

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}. \tag{4}$$

(ii) Recall: It is the accuracy of the classification system in correctly classifying members of class X who are correctly classified as members of class X and is calculated as equation (5). Another name for the recall evaluation criterion is sensitivity. For example, in the problem of predicting customer churn, if class X is the same as the customer class, this measure indicates the accuracy of the system in correctly classifying the customers.

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}. \tag{5}$$

(iii) Precision: This criterion indicates what percentage of the members identified as class X members actually belong to class X and is calculated as

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}. \tag{6}$$

(iv) F-Measure: This criterion is a weighted average between the criteria of accuracy and recall and is used to determine the efficiency of classification systems. This criterion provides more accurate information than the normal average between the accuracy and recall criteria. This criterion is calculated as

$$F - \text{Measure} = 2 * \frac{\text{Precision} * \text{Recall}}{\text{Precision} + \text{Recall}}. \tag{7}$$

(v) Area Under Curve: It indicates the area under the system performance characteristic diagram, and the closer the value of this number to a classification number 1, the more favorable the final performance of the classification method will be evaluated. To calculate the result of the customer churn prediction system in this research, after the system is implemented, it stores the results of its classification in the form of a confusion matrix, so using the results of this matrix, the prior mentioned evaluation criteria are calculated to review and analyze system performance.

4. Results

4.1. Customer Data Collection. A general dataset has been used to evaluate the efficiency of the proposed method for predicting customer churn. This dataset is for a U.S. telecommunication company and is available at https://www.kaggle.com/blastchar/telco-customer-churn. In order to implement the method of predicting customer churn in this research, MATLAB programming language version 2020a has been used. In this dataset, there are 7043 telecommunication subscribers, each of which has 21 information features. Out of 7043, 11 customer data have lost data in some features, so by deleting the information of this 11 missing data, the remains is a dataset that contains 7032 customer information. Thus, there is a problem with dimensions 21. Out of the total number of customers in this dataset, 1869 people are related to the lost customers, who have left the company after a while and 5174 customers are related to those, who have remained loyal to the company. Table 2 shows some of the features of this dataset.

4.2. Simulations Results. After reading the data from the dataset, initial preprocessing was performed on them. This preprocessor involves converting the values of a string variable to numeric variables. Except for properties 3, 6, 19, and 20, which have numeric values, the values of all other properties have string values. So, the values of these variables are converted to numeric values in the preprocessing step. For example, in attribute 4, which has the values yes and no, the value yes is converted to 1 and the value no to 0.

4.3. Select the Feature Using the Fuzzy Entropy Algorithm. In this step, before this algorithm is implemented, it is attempted to manually remove the first feature, Customer ID, from the dataset. The reason for this is that logically, an organization's customer identification number is of no importance in terms of classification, so removing this feature from the dataset will increase the number of features to 20. By running this algorithm, two other properties are removed, which are properties 1 and 5.

Table 2: Customer characteristics in the U.S. telecommunication company database (https://www.kaggle.com).

	Attribute name	Description	DataType	Values
1	customerID	Customer ID	Nominal	7590-VHVEG, 5575-GNVDE,Etc.
2	Gender	Customer gender	Nominal	Female, male
3	SeniorCitizen	Whether the customer is a senior citizen or not	Nominal	0,1
4	Partner	Whether the customer has a partner or not	Nominal	Yes, no
5	Dependents	Whether the customer has dependents or not	Nominal	Yes, no
6	Tenure	Number of months the customer has stayed with the company	Numeric	10,16, etc.
7	PhoneService	Whether the customer has a phone service or not	Nominal	Yes, no
8	MultipleLines	Whether the customer has multiple lines or not	Nominal	Yes, no, No phone service
9	InternetService	Customer's Internet service provider	Nominal	DSL, fiber optic, No
10	OnlineSecurity	Whether the customer has online security or not	Nominal	Yes, no, internet service
11	OnlineBackup	Whether the customer has an online backup or not	Nominal	Yes, no, internet service
12	DeviceProtection	Whether the customer has device protection or not	Nominal	Yes, no, internet service
13	TechSupport	Whether the customer has tech support or not	Nominal	Yes, no, internet service
14	StreamingTV	Whether the customer has streaming TV or not	Nominal	Yes, no, internet service
15	StreamingMovies	Whether the customer has streaming movies or not	Nominal	Yes, no, internet service
16	Contract	The contract term of the customer	Nominal	Month-to-month, one year, two year
17	PaperlessBilling	Whether the customer has paperless billing or not	Nominal	Yes, no
18	PaymentMethod	The customer's payment method electronic check, mailed check, bank transfer	Nominal	Electronic check, mailed heck, bank transfer, credit card
19	MonthlyCharges	The amount charged to the customer monthly	Numeric	85.29, 23.16, etc.
20	TotalCharges	The total amount charged to the customer	Numeric	85.29, 1899.95, etc.
21	Churn	Whether the customer churned or not	Nominal	Yes or No

4.4. Obtain Two Optimal Structures Using Grey Wolf. In order to obtain the appropriate number of layers and the number of neurons in each layer in the proposed method, the grey wolf algorithm is applied. At this stage, the data is randomly divided into three categories: training, validation, and testing. The first category contains 70% of the data used to train the neural network with the structures proposed by the grey wolf algorithm.

First, the grey wolf optimization algorithm starts the optimization process and acquires a structure for the neural network. Then, a neural network is created with this structure and training data is trained to the neural network. After training the neural network with the Levenberg–Marquardt algorithm [21] as one of the best neural network training algorithms, the neural network performance is validated with the dataset.

For example, if the grey wolf algorithm solution is proposed in the first iteration by the best population factor, alpha wolf, it proposes a three-layer neural network with 5, 8, and 10 neurons in the hidden layers one to three, respectively. In this case, a neural network is constructed with such a structure, and the training data is trained to this neural network, and after the completion of the training process, the accuracy of the validation data is calculated based on the evaluation function and the competency of the search agent is determined. This process is performed in different iterations of the algorithm and continues until the number of iterations of the algorithm is exhausted.

After the number of iterations of the algorithm is exhausted, as a result of having used two neural networks in the proposed method, the two best algorithmic solutions are obtained by alpha and beta wolves, as the two structures designated for the neural networks, and two neural networks are created to build a data classifier model.

It is noteworthy that all the parameters of the grey wolf algorithm are similar to the parameters proposed in [20]. Only the number of iterations parameters in this algorithm is considered as 50 iterations and the number of search factors is considered as 30 factors. Additionally, the maximum number of layers considered is a neural network with three layers and also the maximum number of neurons in each layer is a maximum of 20 neurons. The following diagram shows the best structures obtained by the grey wolf algorithm in five different runs of the proposed system.

As can be seen in Figure 4, the grey wolf algorithm has acquired different structures for the neural network in various runs. The reason for this is that each time the algorithm is implemented, the training and validation data are randomly selected, and for this reason, the algorithm obtains different structures appropriate to the training data.

4.5. Build a Classifier Model. After the grey wolf algorithm is implemented in the previous step, the solutions of alpha and beta wolves, which are recognized as the best search agents in the grey wolf algorithm, are as the structures of the feed neural networks. In this step, training of the neural network modules is performed using the Levenberg–Marquardt algorithm.

4.6. Predict the Customer Churn. After building a model for predicting customer churn in the previous step, it is time to evaluate the efficiency and performance of the proposed system. At this stage, the system performance is evaluated using test data. To evaluate the performance of the proposed system at this stage, the confusion matrix and the criteria of accuracy, recall, precision as well as the area under curve are applied. Figures 5–8 show the results of running the

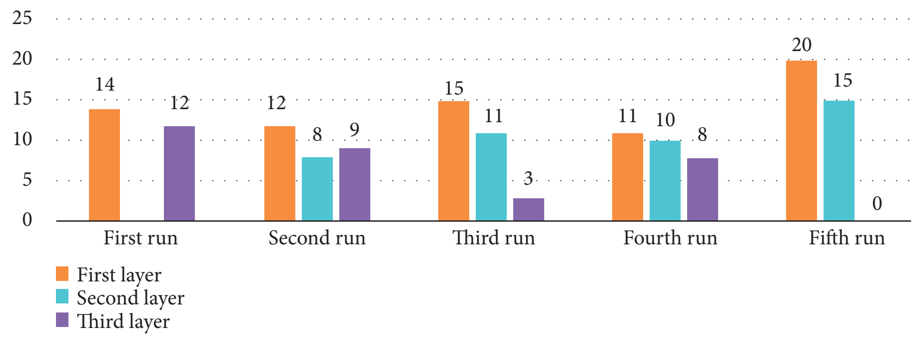

Figure 4: The best structures obtained by the grey wolf algorithm in five different implementations.

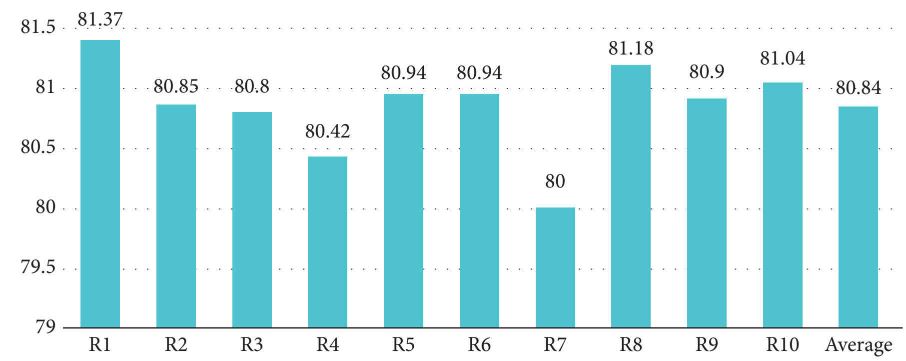

Figure 5: Results of 10 runs of the proposed method in the classification accuracy criterion with an average of 10 runs.

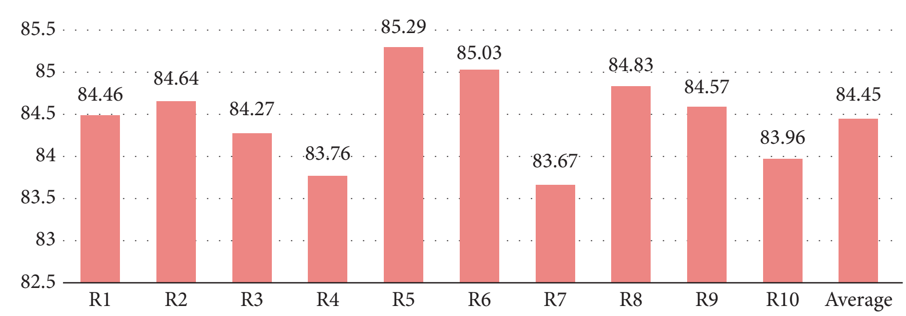

Figure 6: Results of 10 runs of the proposed method in the classification precision criterion with an average of 10 runs.

proposed method regarding the criteria of accuracy, precision, recall, and F_measure, respectively.

As shown in Figures 5–8, averages of 10 different runs of the proposed system in predicting customer churn in the criteria of accuracy, precision, recall, and F_measure are 80.84, 84.45, 91.08, and 87.64, respectively. Besides, the confusion matrix obtained from the best and worst performance of the proposed system on the test data is presented in Figures 9 and 10.

As can be seen from Figure 9, the accuracy of the proposed system in this performance for the test data is 81.4%. Also, it shows that the performance of the proposed system in the criteria of precision, recall, and F_measure is 84.46%, 91.92%, and 88.03%, respectively.

Figure 10 shows the worst performance of the proposed system, and the accuracy in this run for test data is 0.80%. In addition, the performance of the proposed system in the criteria of precision, call and F_measure is 83.67%, 90.9%, and 87.14%, respectively.

Another criterion used to evaluate the performance of classifier systems is area under curve. The closer the area under the system performance characteristic curve diagram is 1, the better the system performance is considered. Figure 11 shows the system performance characteristic diagram in the 10 proposed system runs for the test data. Additionally, Figures 12 and 13 present the area under the system performance characteristic curve diagram in the best and worst performance for training and test data, respectively.

Afterwards, the results of the proposed hybrid system with some of the other methods examined on this dataset are compared. Table 3 shows the results of the proposed method and several other methods in the evaluation criteria of

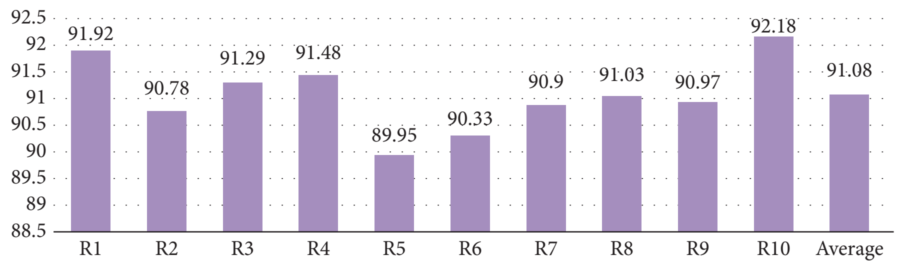

FIGURE 7: Results of 10 runs of the proposed method in the classification recall criterion with an average of 10 runs.

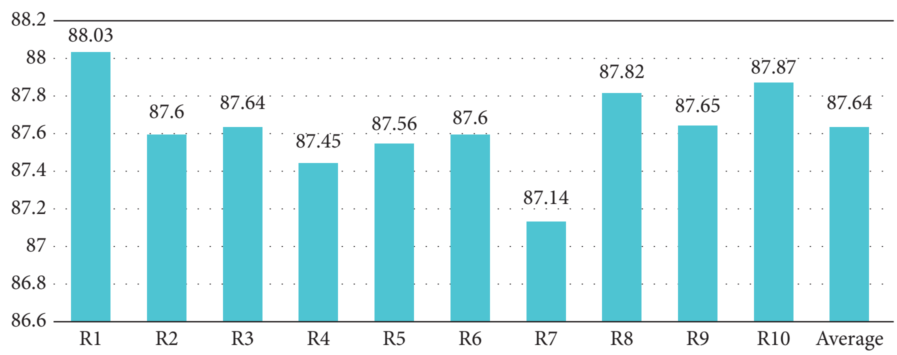

FIGURE 8: Results of 10 runs of the proposed method in the classification recall F_measure with an average of 10 runs.

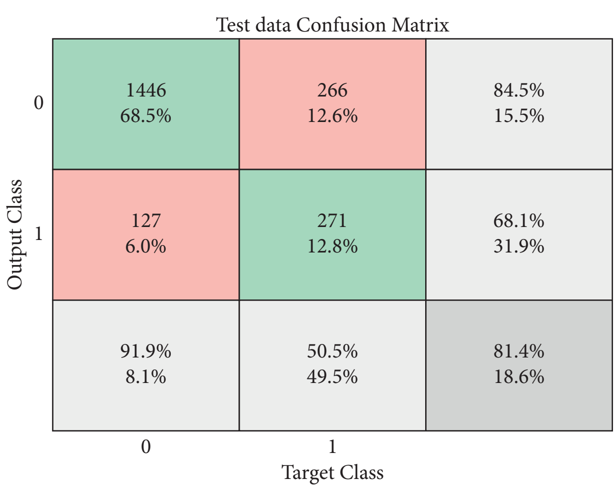

FIGURE 9: Confusion matrix obtained from the best performance of the proposed system in 10 runs.

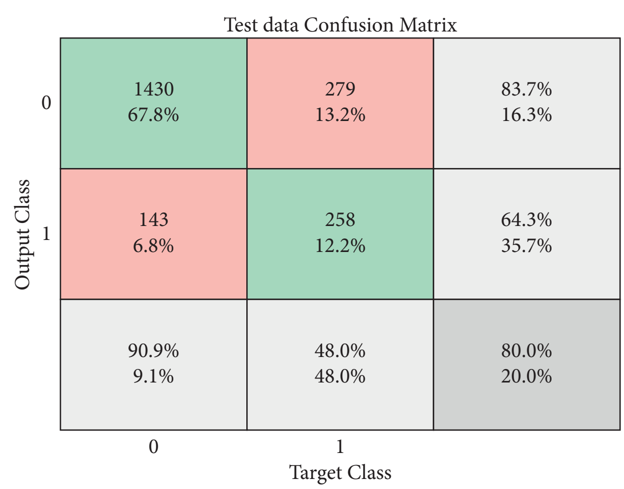

FIGURE 10: Confusion matrix resulting from the worst performance of the proposed system in 10 runs.

accuracy, precision, recall, and F_measure. Results of the proposed method are the average of 10 runs of the proposed method. The results of the proposed method are compared with the results of the methods presented in Halibas et al. [22], i.e., Naive Bayes, generalized linear model, logistic regression, deep learning, decision tree, random forest, and Gradient Boosted Tree.

A noteworthy point in these comparisons is that in these methods a sampling method is used and the results of the methods with and without the sampling method have been examined. However, the results in Table 3 for each of the methods are related to their best results from with and without sampling method.

As can be seen in Table 3, the results of the proposed method are better than other methods in assessing the accuracy, precision, recall, and F_measure criteria. The reasons for the superiority of the proposed method over other methods can be shown as follows

(i) As a result of the use of grey wolf algorithm to select the appropriate structure and architecture for neural networks used in building the predictive model of the proposed system.

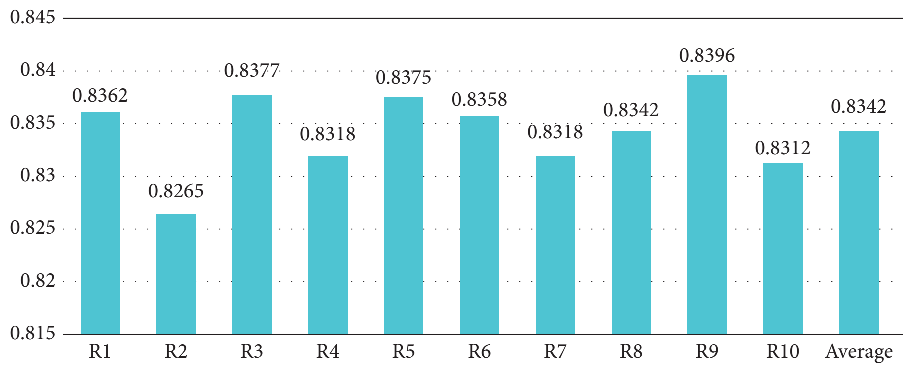

FIGURE 11: Results of 10 runs of the proposed method in the evaluation criterion of area under curve with the average of 10 runs.

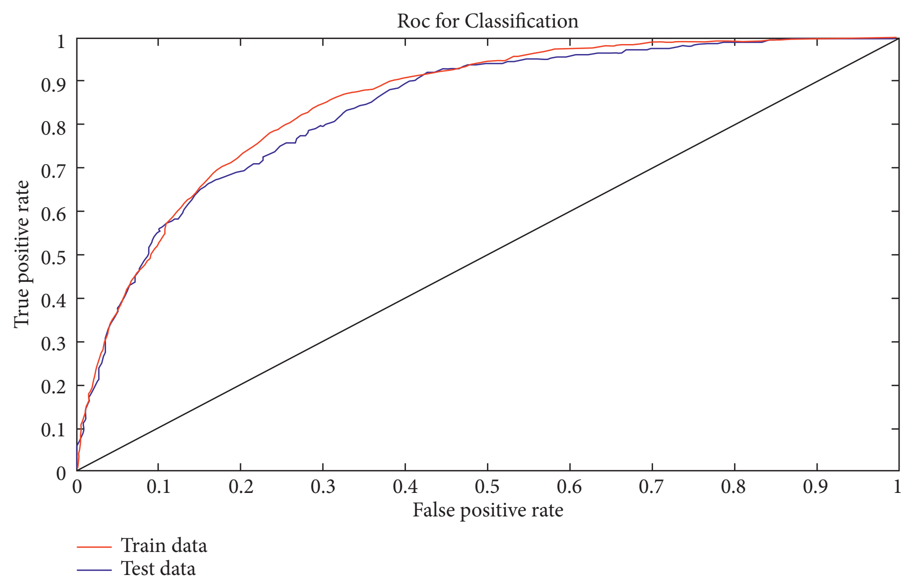

FIGURE 12: The area under the system performance characteristic curve diagram in the best performance.

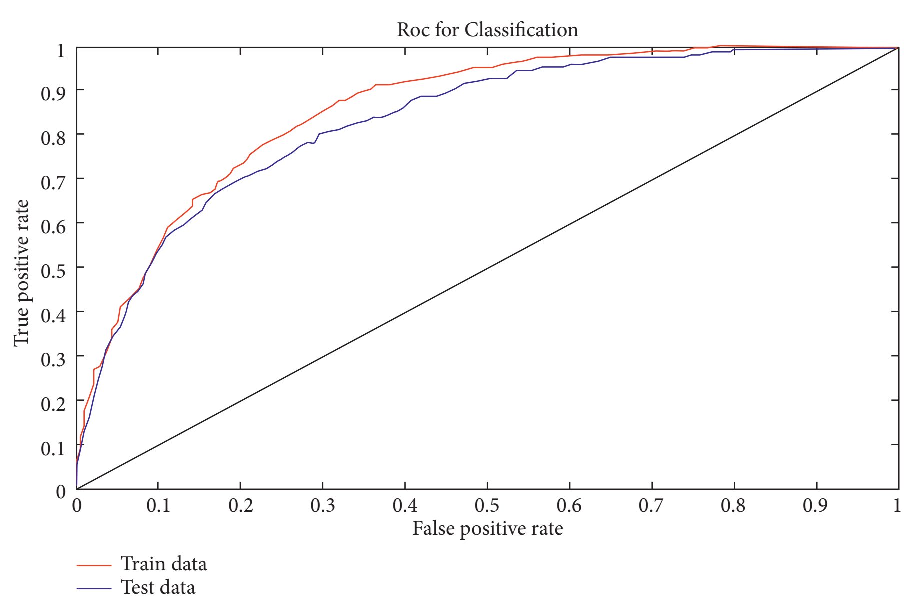

FIGURE 13: The area under the system performance characteristic curve diagram in the worst performance.

Table 3: Comparing the performance of the proposed system and other methods in different evaluation criteria.

No.	Methods	F_measure	Recall	Precision	Accuracy
1	Naive Bayes	72.3	83.9	63.6	73.0
2	Generalized linear model	71.6	72.8	70.4	75.7
3	Logistic regression	71.6	72.9	70.40	75.7
4	Deep learning	72.6	80.9	66.0	74.3
5	Decision tree	70.7	84.6	61.10	70.7
6	Random forest	70.5	70.5	70.6	75.2
7	Gradient boosted tree	76.2	79.6	73.1	79.1
8	The proposed method	**87.64**	**91.08**	**84.45**	**80.84**

(ii) In addition, combining the solutions of the two neural networks and obtaining the final solution makes the proposed method perform better than other methods.

So, it can be used as an efficient method in predicting customer churn of organizations and companies that face the challenge of losing their customers and suffer great financial losses due to the loss of their customers.

5. Conclusion

In this research, it was attempted to propose a hybrid system based on fuzzy entropy measures with similarity classifier, grey wolf algorithm, and artificial neural network to predict the customer churn of companies that suffer from the loss of their customers and financial losses. The use of this system can play a decisive role in the survival of companies in the area of market competition. A company can use this system to identify those customers who might leave the company in the future for various reasons, and take preventive measures based on customer interests and policies.

At first, customer's data of the company was collected. Then, various preprocessing methods were performed on the data, such as conversion of string data into numerical data, and data normalization so that the data could be prepared for the selection of features and training of the neural network. So, the feature selection process was performed using the fuzzy entropy measures with similarity classifier on the dataset. In the next step, the grey wolf optimization algorithm was started and during a process of optimization and different iterations, two optimal structures were obtained for the neural network (i.e., determining the number of layers and the number of neurons in each layer). These structures were used in the phase of building the classifier model to predict customer churn. Finally, after building the classifier model, the proposed system was evaluated with test data. The results of the proposed system performance in predicting customer churn were examined on a customer dataset of a telecommunication company. The results showed that the proposed system had a better performance in different evaluation criteria (accuracy, precision, recall, and F_measure) than other data mining methods.

The contribution of this study is the use of the fuzzy entropy measures with similarity classier to select the optimal features, the grey wolf optimization algorithm to obtain optimal structures for neural networks, and ensemble neural networks to build a model for the aim of predicting customer churn.

Therefore, managers of various organizations including banks, insurance companies, telecommunications industry, stores, online games, online betting, various energy industries, food distributors, and dozens of other businesses can use the proposed system to identify those customers who are likely to leave, gain more profit by taking precautionary measures to retain those customers, and avoid other relevant losses such as financial losses.

Data Availability

The data are contained within the article itself. Upon request, the software file will be provided.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A New Multiechelon Mathematical Modeling for Pre- and Postdisaster Blood Supply Chain: Robust Optimization Approach

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Disaster management is one of the most important actions to protect the property and lives of the victims. Failure to pay attention to logistical decisions of disaster can have irreversible consequences. Therefore, a multiechelon mathematical model for blood supply chain management in disaster situations is proposed in this research. The proposed supply chain includes supplier, central warehouse, reliable distributor, unreliable distributor, distributor, and affected areas. How the proposed model performs is explained as follows: blood is sent from the supplier to warehouses and distribution centers. Also, the capacity of suppliers is limited. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or not to establish a reliable distributor, unreliable distributor, and central warehouse. The amount of blood sent to the centers will also be calculated. One of the contributions of the proposed model is to consider the pre- and postdisaster modes simultaneously. Locating and investigating the flow between centers are also the other contributions of this study. Solving the proposed model using a robust optimization approach is another innovation taken into account in this research. The proposed model is solved using robust optimization, and finally, the results indicate the proper performance of the proposed model.

1. Introduction

One unit of blood can be used once for a patient or several times. In addition to urgent cases, blood therapeutically supports (not for treatment) diseases such as hemoglobin, coagulation, and bone marrow disorders. Having a stable blood supply system requires good services at the level of the blood transfusion organization, a suitable platform such as volunteer donors (donating blood without receiving money and altruistically), rigorous testing systems, a desirable quality system, and a proper monitoring process. Having such a system requires the commitment and support of national health officials and the use of appropriate human, financial, and technological resources [1, 2].

The most important challenge after a major event such as an earthquake is locating relief distribution centers and sending essential goods to the affected areas in order to meet the basic needs of the affected [3]. Disaster relief logistics is one of the main activities in disaster management. What is important in relief logistics is the value of time and delivering the necessary goods and services to the affected in the shortest possible time [4]. One of the important logistic strategies to improve performance and reduce latency is to locate and establish relief distribution centers near these vulnerable areas [5–7]. Thus, the existence of distribution centers in suitable locations of the network, which can properly cover the demand created in these conditions, is of great importance in the successful implementation of relief and rescue operations, and in all cases, the weakness in choosing the right location will increase the likelihood of wasting capital and will ultimately lead to many casualties [8, 9]. The goals pursued in the issue of locating relief distribution centers are to get the location of relief distribution centers closer to the affected areas and reduce the distance (objective minimization function) to deliver services as fast as possible, increase the level of services, and attempt to balance the distance between distribution centers and demand areas (affected people).

The golden time to rescue the injured in an earthquake is only 72 hours [10]. As it is clear, not paying attention to logistical decisions can have harmful financial and human consequences. Thus, minimizing relief time is one of the most important goals of logistics measures. Also, uncertainties in disaster situations make the issue of relief more complicated. Therefore, in this research, a multiechelon mathematical model for blood supply chain management in disaster situations is proposed. The proposed supply chain includes supplier, central warehouse, reliable distributor, unreliable distributor, distributor, and affected areas. How the proposed model performs is explained as follows: blood is sent from the supplier to warehouses and distribution centers. Also, the capacity of suppliers is limited. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or not to establish a reliable distributor, unreliable distributor, and central warehouse. The amount of blood sent to the centers will also be calculated. The amount of blood sent to the centers will also be calculated.

The main contributions of the study are as follows:

(i) Considering the pre- and postdisaster modes simultaneously.
(ii) Locating and investigating the flow between centers.
(iii) Solving the proposed model using robust optimization approach.

2. Literature Review

Shaw et al. [11] provide a mathematical model for location and resource allocation in disaster condition. The uncertainty of the model was fuzzy and was solved using chance-constrained approaches. Minimizing total delivery time and maximizing total affected coverage are the most important goals of their model. Considering loading and unloading times is one of the innovations of this research. The results indicate the proper performance of the proposed model.

Alizadeh et al. [12] provided a multiperiod model for locating relief facilities in natural disaster situations. The main objective of their research is to maximize the coverage of hospitals and distribution centers. The Lagrangian approach is used to solve the proposed model. The results of the case study indicate that an increasing demand reduces the level of coverage of the areas. Alinaghian et al. [13] addressed locating and allocating disaster relief centers in the pre- and post-earthquake conditions. Consideration of temporary relief centers to prevent crowding of the injured is one of the innovations of this research. In order to solve the proposed model, the harmonic algorithm and the forbidden search along with the neighborhood search are used. Numerous numerical examples solved with robust optimization indicate the proper performance of the proposed model. Manopiniwes and Irohara [14] proposed a mathematical model for locating temporary relief centers in flood conditions. The main objective of the research is to minimize supply chain costs such as location and transportation. Therefore, the proposed model is considered as a multiperiod model, as investigated in different periods of demand. One of the considered innovations is the consideration of several modes of transportation. The results of solving the case study indicate the proper performance of the proposed model. Dunn and Gonzalez [15] proposed the development of an adaptive algorithm to increase resilience and the location and allocation of relief bases in flood conditions. Considering possible uncertainty and reliability for the centers are among the innovations considered. ArcGIS software is used to locate the centers. The main objective of the research is to minimize the costs of the whole system, including location costs. The proposed system is solved for various examples and its performance results are satisfactory. Cavdur et al. [16] proposed new strategies for distributing relief goods and human resources in times of disaster. Therefore, a possible two-level model for locating and allocating temporary relief centers is provided. The first level is the predisaster phase and the second level is the postdisaster phase. Minimizing chain costs is done in the first phase and allocating resources to centers is done in the second phase. The results of the sensitivity analysis of the case study indicate that with increasing demand, allocation costs increase sharply. Zhou et al. [17] proposed a mathematical model for blood supply chain management in conditions of uncertainty. The proposed model is implemented using two scenarios of LIFO and FIFO. Considering fairness and minimizing shortage are among the objectives of this research. One of the contributions of the proposed model is demand estimation using discrete event system simulation. Finally, the proposed model is solved using the estimated withdrawal and aging approach. Arani et al. [18] proposed a mixed-integer programming mathematical model for managing blood databases. The considered innovation includes sustainable lateral resupply. Considering inventory-routing decisions is one of the approaches of this research. The proposed model is solved using the multichoice goal programming approach. Shokouhifar et al. [19] proposed a fuzzy mathematical model for blood inventory management. Considering the short lifetime of blood platelets and the cost of corruption is one of the contributions considered. Minimizing the costs of shortages and wastage costs in the supply chain is one of the objectives of the research. The results show that lateral transshipment reduced costs by 3.4%. Shirazi et al. [2] proposed a mathematical model for blood chain management in the Covid-19 outbreak. They first estimated the blood demand using discrete simulation and then the value of this parameter was entered into the mathematical model. The proposed model is solved by the approaches of strength pareto evolutionary algorithm 2 (SPEA-II) and multi-objective gray wolf optimizer (MOGWO). The results show that with increasing demand, the number of established relief bases increases sharply. Khalili-Damghani et al. [20] proposed a mathematical model for cascade disaster management under uncertainty conditions. The considered innovation includes location using the GIS approach. The main objective of the research is to maximize the coverage level. The proposed model is solved using the invasive weed optimization algorithm approach. Table 1 lists the summary of literature review.

One of the research gaps is the lack of attention to the pre- and postdisaster situations simultaneously. Also, locating and examining the flow between the centers are among the research gaps considered. Lack of attention to solving the proposed model using a sustainable approach is another research gap in this research.

3. Problem Statement

This section presents problem assumptions and mathematical modeling as follows:

3.1. Problem Assumptions

(i) Costs related to the shortage of relief items in postdisaster are considered.

(ii) Transportation costs depend on items and scenario.

(iii) Doing transactions between LDCs is allowed. Relief items can be sent from reliable LDCs to unreliable items in case of shortage (ancillary transportation).

(iv) Distribution of relief items in the response phase is assumed for several periods.

(v) Suppliers can procure postdisaster relief items and distribute them in LDC.

In this section, we will model the designed network and describe sets, then parameters, and then variables, and the problem indices are as follows:

(i) I: Supplier

J: Central warehouse

K: Reliable distributor

L: Unreliable distributor

M: Distributor

D: Affected areas

T: Period

c: Product

Now, we have described the problem indices, and we will examine the problem parameters as follows:

g_j: Fixed cost of building a warehouse j

fr_k: Fixed cost of building a reliable distributor k

fu_l: Fixed cost of building an unreliable distributor l

aq_c: Cost of maintenance of relief good c

pc_{ic}: Cost of supplying relief product c before the disaster by supplier i

pc_{cit}: Cost of supply of relief product c by supplier i after the disaster in period t

tc_{ij}: Cost of transportation from supplier i to distributor j

tc_{jm}: Cost of transportation from warehouse j to central distributor m

tc_{md}: Cost of transferring from the central distributor m to the affected area d

tc_{kl}: Cost of transferring the product from a reliable distributor k to an unreliable distributor l

π_{cdt}: Cost of fining a unit of relief product c in affected center d in period t

cap_{ic}: Supply capacity of relief product c by supplier i

w_{cm}: Capacity of distributor warehouse m for relief product c

v_{cj}: Central warehouse capacity j for relief goods c

v_c: Volume of relief product c

φ_m: Percentage of storage capacity that is likely to deteriorate

d_{cdt}: Demand for relief product c by affected area d in period t

Now, the problem parameters have been described, and we will examine the research variables as follows:

qc_{cij}: Transfer of product from supplier i to warehouse j

ql_{cim}: Transfer of product c from supplier i to distributor m before the disaster

q_{cimt}: Transfer of product c from supplier i to distributor m in period t after the disaster

y_{cjmt}: Transfer of product from warehouse j to distributor m in period t

x_{cmdt}: Transfer of product from distributor m to affected area d in period t

u_{cklt}: Transfer of product from a reliable center k to unreliable center l in period t

it_{cmt}: The amount of distributor m from relief product c in period t

b_{cdt}: Deficiency of product c in affected area d in period t

zr_k: Takes a value of 1 if center k is constructed and otherwise zero.

zu_l: Takes a value of 1 if center l is constructed.

δ_j: Takes a value of 1 if center j is constructed.

Now, the indices, parameters, and variables of the research have been described, and we will provide the mathematical model of the research as follows:

Table 1: Literature review.

No	Author	Number of objective functions (single/multiobjective)	Level of satisfaction	Pre/postdisaster decisions	Location	Flow	Multiechelon	Data type (deterministic/uncertain)	Reliable and unreliable centers	Optimization method (deterministic/stochastic/robust/fuzzy optimization)
1	Alizadeh et al. [12]	SO		Po	*		*	U		Sto
2	Alinaghian et al. [13]	SO		Pr/po	*			U		Ro
3	Manopiniwes and irohara [14]	MO	*	Po	*		*	U		Sto
4	Dunn and gonzalez [15]	SO		Pr	*			U	*	Sto
5	Cavdur et al. [16]	SO		Po/Pr		*	*			Dto
6	Zhou et al. [17]	MO	*	Pr		*		U	*	Sto
7	Arani et al. [18]	MO	*	Po				U	*	Ro
8	Shokouhifar et al. [19]	MO	*	Pr		*		U	*	Fo
9	Shirazi et al. [2]	MO		Po	*	*	*	U		Sto
10	Khalili-damghani et al. [20]	SO	*	Po	*			U		Sto
11	This study	MO	*	Pr/po	*	*	*	U	*	Ro

Note. SO, single objective; MO, multiobjective; Po, postdisaster; Pr, predisaster; U, uncertain; Sto, stochastic optimization; Ro, robust optimization; Dto, deterministic optimization; F, fuzzy optimization.

$$\begin{aligned} minz = {} & \sum_j g_j\delta_j + \sum_l fu_l zu_l + \sum_k fr_k zr_k + \sum_i\sum_j\sum_c pc_{ic}qc_{cij} \\ & + \sum_i\sum_m\sum_c pc_{ict}ql_{cim} + \sum_i\sum_j\sum_c aq_c qc_{cij} + \sum_i\sum_m\sum_c aq_c ql_{cim} + \sum_j\sum_m\sum_c\sum_t tc_{jm}y_{cjmt} \\ & + \sum_m\sum_d\sum_c\sum_t tc_{md}x_{cmdt} + \sum_i\sum_m\sum_t (pc_{ict}+tc_{im})q_{cimt} + \sum_k\sum_l\sum_c\sum_t tc_{kl}u_{cklt} + \sum_d\sum_c\sum_t \pi_{cdt}b_{cdt}. \end{aligned} \tag{1}$$

The objective function (1) in the first part will minimize the cost of establishing a local collection center and charity center (consisting fixed cost of building a warehouse, fixed cost of building an unreliable distributor, and fixed cost of building a reliable distributor), and in other parts, it will minimize the cost of sending goods between different levels of the network (consisting supplying relief product c before the disaster by supplier, maintenance of relief good, transportation from supplier to distributor, and cost of fining relief product in affected center):

$$\max z2 = \sum_m\sum_d\sum_c\sum_t \frac{x_{cmdt}}{d_{cdt}}. \tag{2}$$

The second objective function of the problem will maximize the level of satisfaction in order to meet the demand of the affected area:

$$\sum_i v_c qc_{cij} \le v_{cj}\delta_j \quad \forall (j,c), \tag{3}$$

$$\sum_i v_c ql_{cim} \le w_{cm} zr_k \quad \forall (k,m,c), \tag{4}$$

$$\sum_i v_c ql_{cim} \le w_{cm} zu_l \quad \forall (l,m,c). \tag{5}$$

Constraints (4) and (5) will address the issue that no relief goods will be sent until the warehouse and distribution center are activated.

$$\sum_{i} q_{cimt} + \sum_{j} y_{cjmt} + it_{cm(t-1)} = \sum_{d} x_{cmdt} + it_{cmt} + \sum_{l} u_{cklt} \quad \forall (k, m, c, t), \tag{6}$$

$$\sum_{i} q_{cimt} + \sum_{j} y_{cjmt} + \text{it}_{cm(t-1)} + \sum_{k} u_{cklt} = \sum_{d} x_{cmdt} + \text{it}_{cmt} \quad \forall (k, m, c, t), \tag{7}$$

$$\sum_{m} x_{cmdt} + b_{cdt} = d_{cdt} \quad \forall (d, c, t). \tag{8}$$

Constraints (6) and (7) are inventory equilibrium constraints, and constraint (8) states that the amount of goods sent plus the shortage must be equal to the demand of the affected area:

$$\sum_{m}\sum_{t} q_{cimt} \leq cap_{ci} \quad \forall (i, c), \tag{9}$$

$$\sum_{m}\sum_{t} y_{cimt} \leq v_{cj}\delta_{j} \quad \forall (c, j). \tag{10}$$

Constraints (9) and (10) will examine the capacity of the supplier and the central warehouse, which ensures that the maximum number of goods sent is equal to their capacity:

$$\sum_{i} q_{cimt} \leq M\, zu_{l} \quad \forall (l, c), \tag{11}$$

$$\sum_{i} q_{cimt} \leq M\, zr_{k} \quad \forall (k, c, t). \tag{12}$$

Constraints (11) and (12) ensure that it is not possible to send to the distribution center unless reliable and unreliable centers are active:

$$\sum_{d} x_{cmdt} + \sum_{l} u_{cklt} \leq it_{cmt} \quad \forall (k, m, c, t), \tag{13}$$

$$\sum_{d} x_{cmdt} \leq it_{cmt} \quad \forall (m, c, t). \tag{14}$$

Constraints (13) and (14) state that the maximum amount sent to the affected area must be equal to the supply capacity:

$$\sum_{j} y_{cjmt} + \sum_{i} ql_{cim} \leq w_{cm}\varphi_{m} \quad \forall (m,c,t), \tag{15}$$

$$\sum_{j} y_{cjmt} + \sum_{i} q_{cimt} + it_{cm(t-1)} \leq w_{cm} \quad \forall (k,m,c,t), \tag{16}$$

$$\sum_{j} y_{cjmt} + \sum_{i} q_{cimt} + \sum_{k} u_{cklt} + it_{cm(t-1)} \leq w_{cm}\varphi_{m} \quad \forall (l,m,c,t). \tag{17}$$

Constraints (15) to (17) examine the capacity of the distribution center before and after the disaster:

$$\sum_{d} x_{cmdt} \leq M\, zr_{k} \quad \forall (k, m, c, t, l), \tag{18}$$

$$\sum_{d} x_{cmdt} \leq M\, zu_{l} \quad \forall (l, m, c, t), \tag{19}$$

$$u_{cklt} \leq M\, zr \quad \forall (k, m, c, t, l), \tag{20}$$

$$u_{cklt} \leq M\, zu_{l} \quad \forall (k, m, c, t, l). \tag{21}$$

Constraints (18) to (21) state that no goods must be sent until the distribution center is active.

3.2. Solution Method: Scenario-Based Robust Optimization. Suppose U is a set of all possible scenarios that may occur in the future and S is a specific scenario of this set. These two concepts are in fact the stability of the model and response. In the response stability, the optimal response of the model for each scenario is close to the desired value while the response of the model for each scenario in the stability of the model is nearly practical:

$$Min\, z = \sum_{s} pr_{s}(Z) + A \sum_{S} pr_{s} \left[Z - \sum_{S} pr_{s} \right]^{2}. \tag{22}$$

The first part is the mean and the second part is the variance of the objective function. A is the weight of variance depending on the decision-maker and is obviously chosen by the degree of risk aversion in the decision-maker. However, since the above function is nonlinear in nature, according to Yu [21], the following function will be used in the problem:

$$Min\, z = \sum_{s} (Z) + A \sum_{S} pr_{s} \left| Z - \sum_{S} pr_{s} \right|. \tag{23}$$

The following constraint will be used to linearize the above equation:

$$A \sum_{S} pr_{s} \left(g_{s}^{+} - g_{s}^{+}\right). \tag{24}$$

Therefore, the model under the scenario will be as follows:

$$
\begin{aligned}
&minz = \sum_s pr_s \left[\begin{array}{c} \sum_j g_j \delta_j \sum_l fu_l zu_l + \sum_k fr_k zr_k + \sum_i \sum_j \sum_c \sum_s pc_{ic} qc_{cijs} + \sum_i \sum_m \sum_s \sum_c pc_{ict} ql_{cims} \\ + \sum_i \sum_j \sum_s \sum_c aq_c qc_{cijs} + \sum_i \sum_m \sum_s \sum_c aq_c ql_{cims} + \sum_j \sum_m \sum_c \sum_s \sum_t tc_{jm} y_{cjmts} \\ + \sum_m \sum_d \sum_c \sum_s \sum_t tc_{md} x_{cmdts} + \sum_i \sum_m \sum_s \sum_t (pc_{ict} + tc_{im}) q_{cimts} + \sum_k \sum_l \sum_c \sum_s \sum_t tc_{kl} u_{cklts} \\ + \sum_d \sum_c \sum_s \sum_t \pi_{cdt} b_{cdts} \end{array} \right] + A_1 \sum_S pr_s (g_s^+ - g_s^+) + A_2 \sum_J \sum_s pr_s \Delta_{sj} in\,f\,pen \\
&\sum_i v_c qc_{cijs} = v_{cj}\,\delta_j \quad \forall (j, c, s), \\
&\sum_i v_c ql_{cims} = w_{cm} zr_k \quad \forall (k, m, c, s), \\
&\sum_i v_c ql_{cims} = w_{cm} zu_l \quad \forall (l, m, c, s), \\
&\sum_i q_{cimts} + \sum_j y_{cjmts} + it_{cms(t-1)} = \sum_d x_{cmdts} + it_{cmts} + \sum_l u_{cklts} \quad \forall (k, m, c, t, s), \\
&\sum_i q_{cimts} + \sum_j y_{cjmts} + it_{cms(t-1)} + \sum_k u_{cklts} = \sum_d x_{cmdts} + it_{cmts} \quad \forall (k, m, c, t, s), \\
&\sum_m x_{cmdts} + b_{cdts} = d_{cdts} \quad \forall (d, c, t, s), \\
&\sum_m \sum_t q_{cimts} \le cap_{ci} \quad \forall (i, c, s), \\
&\sum_m \sum_t y_{cjmts} \le v_{cj}\,\delta_j \quad \forall (c, j, s), \\
&\sum_i q_{cimts} \le M\, zr_k \quad \forall (k, c, t, s), \\
&\sum_i q_{cimts} \le M\, zu_l \quad \forall (l, c, s), \\
&\sum_d x_{cmdts} + \sum_l u_{cklts} \le it_{cmts} \quad \forall (k, m, c, t, s), \\
&\sum_d x_{cmdts} \le it_{cmts} \quad \forall (m, c, t)/ \\
&\sum_j y_{cjmts} + \sum_i ql_{cims} \le w_{cm} \varphi_{ms} \quad \forall (m, c, t, s), \\
&\sum_j y_{cjmts} + \sum_i ql_{cims} \le w_{cm} \varphi_{ms} \quad \forall (m, c, t, s), \\
&\sum_j y_{cjmts} + \sum_i q_{cimts} + it_{cms(t-1)} \le w_{cm} \quad \forall (k, m, c, t), \\
&\sum_j y_{cjmts} + \sum_i q_{cimts} + \sum_k u_{cklts} + it_{cms(t-1)} \le w_{cm} \varphi_m \quad \forall (l, m, c, t) \\
&\sum_d x_{cmdts} \le M\, zr_k \quad \forall (k, m, c, t, s) \\
&\sum_d x_{cmdts} \le M\, zu_l \quad \forall (l, m, c, t, s) \\
&u_{cklts} \le M\, zr_k \quad \forall (k, m, c, t, l) \\
&u_{cklts} \le M\, zu_l \quad \forall (k, m, c, t, l) \\
&z - \sum_s pr_s = (g_s^+ - g_s^-)\, \forall (s) \\
&g_s^+ \le tt * m\, \forall (s) \\
&g_s^- \le (1 - tt) * m.
\end{aligned}
\tag{25}
$$

4. Results

In this section, we will first examine the problem in small dimensions in certain conditions and then we will solve the problem in conditions of uncertainty. For this purpose, we should first describe the dimensions of the problem, then initialize the various parameters of the model, and then examine the research variables and how they perform in the model (Table 2).

Now, the dimensions of the problem have been determined, and we will initialize the parameters for this purpose. The first parameter that will be determined is the amount of product use, which is specified based on Table 3.

As can be seen in the table above, the fixed cost of building a central warehouse is described. After this, we need to describe the fixed cost of building a reliable and unreliable distribution center and the cost of maintaining relief goods, as listed in Table 4.

Table 2: Dimensions of the problem.

I	j	m	k	l	c	d	T
5	4	6	6	6	3	10	3

Table 3: Fixed cost of building central warehouse j.

J1	J2	J3	J4
20857	242163	227519	215057

Table 4: Fixed cost of building a reliable and unreliable distribution center and maintenance cost of relief goods.

K1	**K2**	**K3**
114611	111203	117492
L1	L2	L3
97125	81342	90004
C1	C2	C3
70	62	70

Table 5: Cost of supply of relief goods before the disaster.

	c1	c2	c3
i1	48	41	46
i2	42	43	47
i3	44	44	44
i4	41	42	46
i5	48	42	47

Table 6: Cost of supply of relief goods after the disaster.

		T1	T2	T3
i1	C1	58	53	51
i1	C2	55	52	59
i1	C3	53	53	56
i2	C1	57	56	55
i2	C2	54	51	53
i2	C3	50	53	52
i3	C1	56	56	58
i3	C2	53	57	58
i3	C3	56	53	51
i4	C1	51	56	55
i4	C2	50	58	51
i4	C3	52	55	58
i5	C1	52	50	56
i5	C2	56	54	54
i5	C3	52	52	51

Table 7: Cost of transferring relief goods from supplier to central warehouse.

	j1	j2	j3	j4
i1	29	24	28	23
i2	21	27	21	22
i3	20	23	25	22
i4	22	23	23	23
i5	30	30	24	24

Table 8: Cost of transferring relief goods from supplier to central distributor.

	m1	m2	m3	m4	m5	m6
i1	33	29	34	26	32	26
i2	31	26	25	29	30	31
i3	27	29	28	27	34	29
i4	26	29	29	28	34	27
i5	28	26	29	26	29	28

Table 9: Transfer cost of relief goods from reliable distributor to unreliable distributor.

	L1	L2	L3
K1	18	11	20
K2	16	12	16
K3	13	19	19

Table 10: Transfer cost of relief goods from distributor to the affected area.

	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10
m1	17	17	21	22	16	17	19	17	22	23
m2	17	19	22	23	21	25	15	17	16	20
m3	16	22	16	20	23	20	20	15	20	20
m4	25	17	17	15	17	16	15	23	21	15
m5	17	25	18	21	18	21	17	20	19	23
m6	20	19	21	24	18	15	24	21	18	25

Table 11: Total probabilities of possible scenarios.

Scenario	1	2	3
Probability	0.35	0.40	0.25

Table 12: Different parameters under possible scenarios.

Parameter	Intended value
pc_{citS}	U (200000, 2500000)
π_{cdtS}	U (100, 120)
d_{cdtS}	U (100, 300)
$\varphi_{\mathbf{mS}}$	U (0.2, 0.4)

Table 13: Response of the objective function under different scenarios.

Objective function	s1	s2	0
	5380553	5398653	5377553

Table 14: Robustness analysis of the objective function.

$\mathbf{A}_1$	$\mathbf{A}_2$	Infpen	Objective function
80	40	100	8234814
80	60	100	10675414
80	80	100	13116014
80	120	100	17997214

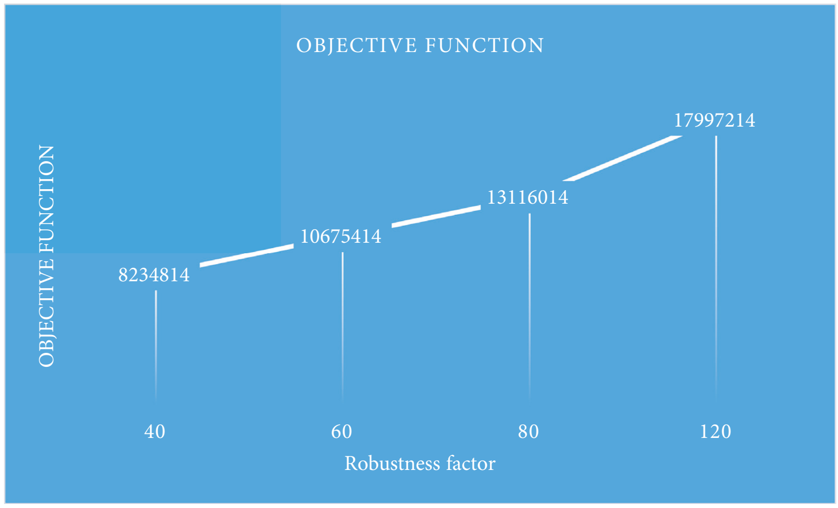

FIGURE 1: Changes in the objective function relative to the robustness factor.

Now, we have to describe the cost of supplying relief goods before the disaster, as listed in Table 5.

Now, the cost of supplying relief goods before the disaster has been determined, and we must now address the cost of supplying relief goods after the disaster, as listed in Table 6.

Now, after the cost of supplying the relief goods has been determined, we have to address the transfer cost of the relief goods, as listed in Table 7.

Table 8 lists the cost of transferring relief goods from supplier to central distributor.

Table 9 lists the transfer cost of relief goods from reliable distributor to unreliable distributor.

Now, we need to determine the cost of transporting relief goods from the distributor to the affected area, as listed in Table 10.

4.1. Examination of the Problem in Conditions of Uncertainty. In order to examine the problem in conditions of uncertainty, it is first necessary to determine values of the parameters in the conditions of uncertainty in the research and then examine the results. For this purpose, it is first necessary to determine scenarios for the occurrence of an accident with certain probabilities, as listed in Table 11.

Now, the different scenarios have been identified, and we need to determine the values of the parameters that have uncertainty in the research, as listed in Table 12.

Now, in order to understand what effect robust optimization has on the objective function of the problem, we will examine different objective functions under different scenarios, and the results are listed in Table 13.

Now, after examining the objective function under different scenarios, the worst value of the objective function must be determined under uncertainty conditions, which is 5398653, that is, the worst answer of the system.

4.2. Analysis of Objective Function Relative to Standard Deviation of Response A_2. In order to investigate how robust optimization works, we intend to perform a sensitivity analysis on the effect of robust optimization on the objective function. For this purpose, we will analyze the objective function based on Table 14, and since the problem is minimization, it has to have an ascending value with an increasing standard deviation of the objective function.

As can be seen from Figure 1, by increasing the robustness coefficient, the response of the objective function increases, which indicates the proper performance of the model.

TABLE 15: Robustness analysis of the objective function relative to the amount of the fine.

$\mathbf{A_1}$	$\mathbf{A_2}$	Infpen	Objective function
80	60	0	0
80	60	10	5895794
80	60	100	10675414
80	60	200	17997214
80	60	300	25319014
80	60	500	39962614
80	60	750	58267114
80	60	1000	76571614

4.3. Changes of the Objective Function Relative to the Amount of the Fine. Now, in order to determine how the objective function changes relative to the amount of the fine, the following experiment has been designed, in which the constant coefficients and the degree of violation of the objective function have increased (Table 15 and Figure 2).

5. Managerial Insight and Practical Implication

The benefits of the proposed model in this study can be useful for the Blood Transfusion Organization, the Red Cross, the Crisis Relief Organization, the municipality, and ultimately all people. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or

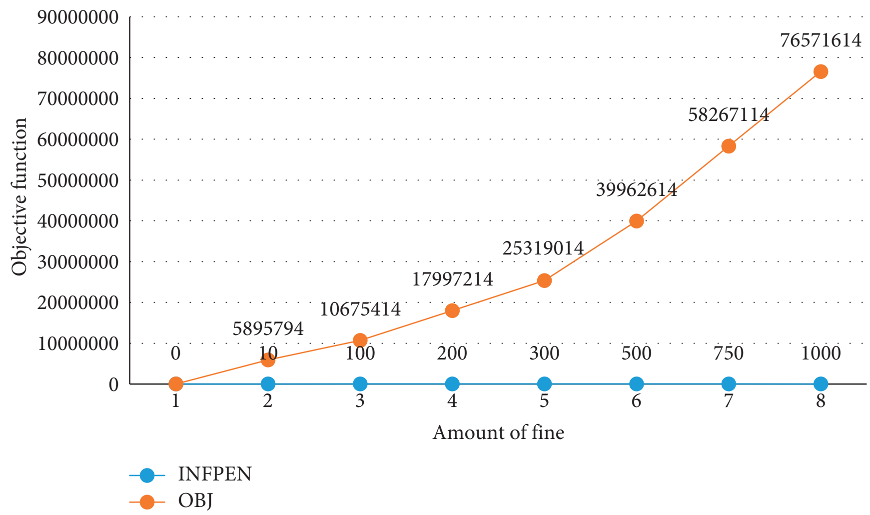

Figure 2: Changes in the objective function relative to the robustness factor.

not to establish a reliable distributor, unreliable distributor, and central warehouse. Also, maximizing the satisfaction level during crisis relief can build the trust of the community. Therefore, this study intends to provide a model to meet the needs of managers in these conditions. Also, considering that in response conditions, the main goal is usually a quick response to minimize costs and maximize the satisfaction of the injured; in the presented model, an attempt has been made to provide a plan taking into account the real logistical conditions.

6. Conclusion

In this research, a mathematical model to minimize logistics costs in the blood supply chain in disaster situations is proposed. One of the innovations of the proposed model is to consider the pre- and postdisaster modes simultaneously. Locating and examining the flow between centers are also the other contributions of this study. Solving the proposed model using the robust optimization approach is another innovation considered in this research. The benefits of the proposed model in this study can be useful for the Blood Transfusion Organization, the Red Cross, the Crisis Relief Organization, the municipality, and ultimately all people.

In order to examine the problem in conditions of uncertainty, it is first necessary to determine values of the parameters in the conditions of uncertainty in the research and then to examine the results. For this purpose, it is first necessary to determine scenarios for the occurrence of an accident with certain probabilities. Also, we will analyze the objective function, and since the problem is minimization, it has to have an ascending value with an increasing standard deviation of the objective function. Finally, the robust optimization method was used to solve the problem, which examined the problem in conditions of uncertainty. Future suggestions are as follows: It is interesting to extend the proposed model to perishable relief items. Also, the dangers of disruptions in roads and distribution of the last item and the problem of routing for vehicles can be studied in the future. The resilient supply chain may not be the least expensive supply chain, but the resilient supply chain can overcome uncertainties and disruptions in the business environment. The competitive advantage of the supply chain not only depends on low costs, high quality, reduced latency, and high level of service but also on the ability of the chain to avoid disasters and overcome critical situations, and this is the resilience of the supply chain. Resilience is the ability of the supply chain to overcome unpredictable events. The purpose of creating resilience in the supply chain is to prevent the chain from moving toward adverse conditions. Incidents such as the eruption in Iceland made companies aware of how little control they have over the risks they face, but today, there are companies that are able to return to normal or even get better than before after severe disturbances and fluctuations. Therefore, it is suggested that we try to increase the resilience of the problem by considering redundancy [2, 9].

This research, like other research, is not without limitation and assumptions. Therefore, the limitation of the research is expressed as follows: as there was no official database for some parts of cost elements, the driver's estimations and blood transfusion center officers were asked to help.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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