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Research Article

Multiobjective Three-Level Supply Chain Management Problem Under Uncertainty Using Gravitational Search Algorithm

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A supply chain is a set of resources, facilities, customers, products, and methods of inventory control, purchasing, and distribution. Every manufacturer or distributor has a subset of the supply chain that they have to manage and implement beneficially and efficiently for their survival and growth. Therefore, the production and delivery of products in the proper amounts and at the right time is as important as minimizing costs as well as customer satisfaction. Considering these reasons, supply chain network optimization includes decisions from many different aspects. In this study, a single-product three-level supply chain with manufacturer-customer loops is considered that customer demand, percentage of returned products from customers, and delivery time from manufacturers to customers are considered as fuzzy variables with uncertainty. Simultaneously considering the issues of selecting suppliers and distributors and determining the effective customers in the system is under uncertainty. This project aims to provide a model that, in addition to integrating the conflicting goals of the loops, also increases the number of uncertain parameters of the model. Therefore, the objectives of the proposed model are to maximize product quality; minimize total cost; minimize delivery time from distributors to customers; and maximize revenue from selling products to customers.

1. Introduction

It has been nearly three decades since the issue of supply chain management that has been raised, and according to available statistics, countries and organizations that have used this knowledge have made significant progress in their respective fields and have made huge profits and large financial savings from applying this attitude [1]. Also, people as customers have benefited from this. Given the many benefits that have been achieved due to the use of supply chain management, today, this philosophy is gaining special acceptance among different organizations and countries, and the number of its enthusiasts is increasing every day. Moreover, during the last three decades, the scientific and academic attitude toward the issue of supply chain management has been very positive, and many studies have been written in the form of papers in this regard. Today, communication management in a supply chain referring to a topic that we call supply chain management (SCM). Simply put, a supply chain is not just a chain of business activities in the form of one-to-one or firm-to-firm communications, but a network of business activities and communications between them [2]. SCM offers opportunities for a positive intensification of intracompany and intercompany integration and management. In this case, SCM is associated with the advantages of business processes and provides a new method to manage business activities and relationships with other members of the supply chain. The concept of SCM is defined by the integration of logistics services along the supply chain toward the integration and management of key business processes along the open supply chain. Based on this clarification of the difference between SCM and logistics, in 2003, the Logistics Management Association introduced a modified definition of logistics. This modified definition clearly states the position of the Logistics Management Association, which introduces "logistics management" as part of the SCM. This modified definition is in such a way that it is the logistics of that part of the supply chain management that plans, uses, and controls the efficiency and effectiveness of forward and backward flow as well as the storage of products, services, and related information between the starting point of the chain and the end point of consumption in order to meet the needs of customers [3, 4].

Most organizational architectures are linear and consider the value chain model, producing and disposing products as a result of which the natural resources available on the planet are consumed. Therefore, sustainable development agendas are increasingly calling for supply chains to shift from linear to closed-loop models, in which circularity ideals such as reuse, remanufacturing, and recycling become the 'new normal' practices. Embedding circularities within supply chains thus has been considered by many researchers, practitioners, and policymakers as an approach for businesses to improve its sustainability outcomes in occupations [5]. A number of companies are seeking solutions to accelerate the scale-up and transition efforts towards circular supply chains. This change requires not only a product, process, and technological innovation but also business model innovation that has to consider novel recycling systems to bring back used products. Also, making supply chains circular cannot be achieved by a specific firm, as it requires collaboration between the organizations across the supply chains and other stakeholders from similar and/or diverse sectors. In general, a change in one organization's business model will affect the business activities of other organizations in their supply chains. Therefore, a systemic approach for managing better utilization of materials, energy, and other valuable resources through higher rates of recycling, reuse, and remanufacturing is imperative for success. However, there is limited theoretical and empirical knowledge about this phenomenon of interest [6]. The need to meet global demand in a sustainable and ever-increasing way indicates adequate and efficient management of supply chain operations. Considering the improved sustainability in supply chains, many companies have begun to incorporate new or recycled materials, cleaner technologies, and new organizational and logistics measures to increase their operational, economic, and social performance [7]. 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 are still dangerously unsustainable. If there is no change in the way of supply, production, delivery, use, recovery, and remanufacturing of products, the world will consume a lot of natural resources at its current level of consumption [8, 9]. Today, the closed-loop supply chain has become a strategic variable for organizations even beyond the environmental aspects. There is also an important path that increases the focus of the study in this regard, and considering the social and economic scenarios that affect different stakeholders in a broader sense has been developed towards a more sustainable manufacturing system as research on the change methods [11, 12].

The important point is that we generally face multiple uncertainties in planning. One of the uncertainties we often face is the amount of demand and related costs that may occur. Therefore, in this problem, supply and demand parameters are considered uncertain, and this uncertainty is defined using a set of separate scenarios.

In this research, the fuzzy inference system is used to estimate the amount of random uncertain demands required. The fuzzy inference system is a systematic process for converting a knowledge base into a nonlinear map. For this reason, knowledge-based systems (fuzzy systems) are used in engineering and decision-making applications [12]. Mamdani and Asilian used the fuzzy inference system in 1975 to control the combination of a steam engine and a boiler using a combination of language control rules in the experiences of human operators [13]. A fuzzy system has the following components: Figure 1 shows the steps of a fuzzy inference system.

(1) A fuzzifier at the input that converts the numerical value of the variables into a fuzzy set.
(2) A fuzzy rule base that is a set of if-then rules.
(3) A fuzzy inference engine that converts inputs to outputs with a series of actions.
(4) A defuzzifier that converts the fuzzy output to a crisp number.

According to the above, in this research, a channel selection system for transportation planning in the supply chain is introduced. This system can be used as part of the set of supply chain planning systems and helps managers effectively solve logistics problems. Due to the fact that transportation planning has different characteristics in different industries, the most important contribution of this research is to provide a framework for structured classification of this problem. Also, while providing the design and optimization approach of this system, the characteristics of the model components and how the optimization algorithm relates to the model will be explained. Then, the problem will be solved using a hybrid evolutionary algorithm based on the gravitational search algorithm. Therefore, the main advantages of the research are as follows:

(i) presenting the mathematical model of a three-level supply chain by considering the fuzzy parameters of customer demand, returned product, and delivery time from the manufacturer to the customer.
(ii) presenting an overall framework to consider conflicting objectives in the supply chain with a number of uncertain model parameters.

The most important question of this research that has formed in the mind of the researcher is

(i) can the problem of transportation channels in the supply chain be solved using the gravitational search algorithm?

The rest of this paper is as organized as it is clear. In Section 2, a literature review is provided. In Section 3, the research modeling method and problem-solving approach are introduced. In Section 4, the main results obtained from the application of the proposed model are provided. Finally,

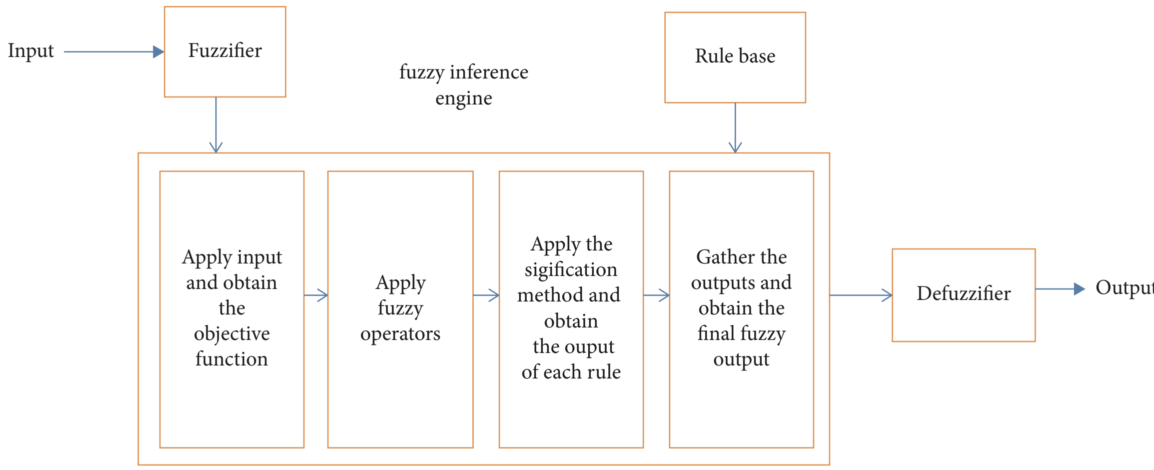

Figure 1: Steps of the fuzzy inference system.

in Section 5, a general conclusion with suggestions for future research is provided.

2. Literature Review

In this section, a number of studies that have been conducted in this area are introduced. For example, Chobar et al. [14] designed a multiobjective hub-spoke network of perishable tourism products. In order to consider the perishable factor of the products, some collection centers are considered for the products that perish. Accordingly, the combination of hub-spoke network and supply chain are assessed here. Moreover, this combination is to use transportation discounts in the supply chain network. Tirkolaee et al. [15] developed a novel mathematical model to design a sustainable mask closed-loop supply chain network (CLSCN) during the COVID-19 outbreak for the first time. A multiobjective mixed-integer linear programming (MILP) model is proposed to address the locational supply, production, distribution, collection, quarantine, recycling, reuse, and disposal decisions within a multiperiod, multiechelon, and multiproduct supply chain. Additionally, sustainable development is studied in terms of minimizing the total cost, total pollution, and total human risk at the same time. Fu et al. [16] studied an inverse channel in a dynamic closed-loop supply chain system consisting of manufacturers and retailers. Based on the dynamic model, the decisions and benefits of the members in the mentioned chain are investigated in different inverse channels that take into account the quantitative characteristics of the products. The results show that the optimal collection decisions for the given quantitative characteristics of products are diverse at different development levels of the chain. Furthermore, a transfer payment coordination mechanism based on the Nash bargaining model is proposed to address the objective inconsistency between CLSC and its members. Rezaei Kallaj et al. [17] presented a relief supply chain under crisis conditions, taking into consideration the blood supply chain. For this purpose, they proposed a model for the routing of blood receivers under crisis conditions considering different blood groups. Khorshidvand et al. [18] in their study, proposed a new hybrid method in which supply chain decisions and closed-loop supply chain objectives are simultaneously involved. First, this decision-making approach maximizes profits and then minimizes CO2 emissions. A new nonlinear programming (NLP) model has been developed based on green quality return rate sensitivity and maximum customer tolerance, while demands are clear. Maadanpour Safari et al. [19] presented a triobjective mathematical model that is proposed for the transportation-location-routing problem. The model considers a three-echelon supply chain and aims to minimize total costs, maximize the minimum reliability of the traveled routes, and establish a well-balanced set of routes. In order to solve the proposed model, four meta-heuristic algorithms, including multi-objective grey wolf optimizer (MOGWO), multi-objective water cycle algorithm (MOWCA), multi-objective particle swarm optimization (MOPSO), and nondominated sorting genetic algorithm-II (NSGA-II), have been developed. Jahangiri et al. [20] provided a ranking for key resources in the humanitarian supply chain in the emergency department of an Iranian hospital using a hybrid decision-making method under pandemic conditions. Goodarzian et al. [21] designed a multiobjective, multilevel, multiproduct, and multiperiod problem for a sustainable medical supply chain network. Three hybrid meta-heuristic algorithms, namely, ant colony optimization, fish swarm algorithm, and firefly algorithm, are suggested, hybridized with variable neighborhood search to solve the sustainable medical supply chain network model. González-Sánchez et al. [7] investigated value chains to visualize the links and interactions between different stages and actors to understand the complexities of the issue. The ultimate goal of this study is to achieve a conceptual framework for the study of circular supply chains that uses the main theoretical perspectives in the strategic management literature. Four new dimensions have been identified to support the development of these supply chains; greater intensity in the relationships established in the supply chain; logistics and organizational compatibility; intelligent technologies; and a functional environment. From the results obtained from this research, it can be concluded that for the new development of the chain, it should be possible to establish more frequent and closer relationships with the actors. These relationships will be developed within a compatible organizational and logistical framework incorporated into the new business model patterns. However, environmental trade dimensions such as legal and financial frameworks must be included in it. In their study, Khandelwal and Barua [22] provided a perspective for the implementation of closed-loop supply chain management in the plastics industry in emerging economies, especially India. It integrates the philosophy of circular economy (CE) into supply chain management and offers a new perspective on sustainability. However, it is difficult to implement a closed-loop supply chain due to the multiple obstacles. Therefore, this study was conducted to investigate and prioritize barriers to the implementation of closed-loop supply chain measures in the Indian plastics industry. It uses this two-stage method to identify and prioritize barriers to the implementation of a closed-loop supply chain. A total of 24 barriers were identified through an extensive literature review and expert opinions in five main groups. A fuzzy analytic hierarchy (AHP) was used to rank the barriers. A fuzzy framework is considered to control uncertainty and ambiguity. To illustrate the proposed model, an experimental case is taken from the Indian plastics industry. A sensitivity analysis was carried out to investigate the capability of the model. The results show that the lack of tax reduction policies and poor enforcement of laws and regulations to protect the environment are the most prominent barriers, according to the results of this study. The findings of this study can be used as a benchmark for managers and policymakers in the effective implementation of closed-loop supply chains. In their study, Farooque et al. [8] first classified different terms related to supply chain sustainability and then conceptualize a single definition of a cyclical supply chain. Using this definition as a basis, they then investigated a structured literature review of 261 research papers on the current state of circular supply chain research. According to the results of the study, researchers want more studies in areas that are less considered but important. These aspects include biodegradable packaging, circular supply chain cooperation and coordination, circular supply chain drivers and barriers, circular consumption, product commitments, and technologies. In their study, Yang et al. [6] addressed the business model innovation for circular supply chains and suggested that business models of manufacturing service systems can, by creating value in domestic circles, increase prolonged use loops of the supply chain loop. The method provided in this paper is to adopt a heuristic method from a large Chinese manufacturing company that uses a traditional product-based business model and three types of manufacturing business models. De Angelis et al. [10] provide introductory statements on the development implications of what we call the circular supply chain, which in the study is defined as the principles of circular economy in supply chain management. The findings of this study are based on the following arguments, which are: (A) the change from product ownership to leasing and access to supply chain relationships; (B) € relationship between structural flexibility and start-ups in regional-local loops; (C) open and closed material loops in technical and biological cycles; (D) closer cooperation inside and outside the borders of the industry; and €(E) public and private procurement in industry or services as a lever for scaling circular business models. This study also discusses the meaning of the principles of circular economy in terms of supply chain challenges and concludes on the limitations and future research agenda. Changing supply chains from linear to closed-loop models is an important step towards a circular economy.

2.1. Research Gap. According to the points mentioned among the existing theoretical studies, the most important gaps that can be observed from studying the research have been identified as follows:

(i) In most of the papers, the number of layers considered in the logistics network is small. While considering the different parts of the logistics network as integrated in the models, which makes the model closer to the real-world conditions because in reality, an optimal interaction must be carried out between all these parts and considering only a small part of this network and optimizing it takes it away from the real situation. One of the research gaps in this research is not paying attention to the different levels of inventory in each of the layers.

(ii) Many papers have provided one-objective models; however, multiobjective models are used in engineering planning to create balance and get closer to reality. The main objective of many papers has been to minimize the total cost or minimize the total time.

(iii) In most papers, the authors have considered their parameters as certain, while in the real world and in crisis situations, we face many uncertainties for various parameters such as supply, demand, time, place, route, cost, etc. Considering the parameters as certain is a simplifying assumption that greatly takes the model far away from the real world.

(iv) Many papers have used examples generated with random numbers to validate their models while it is better to validate the models using real-world examples and write the models for real case studies. In fact, case studies and practical studies in this area should be increased.

The most important contribution of this research is to provide a framework for structured classification of this problem. The main contributions to the fulfillment research gap are as follows:

(i) presenting the mathematical model of a three-level supply chain by considering the fuzzy parameters of customer demand, returned product, and delivery time from the manufacturer to the customer.

(ii) presenting an overall framework to consider conflicting objectives in the supply chain with a number of uncertain model parameters.

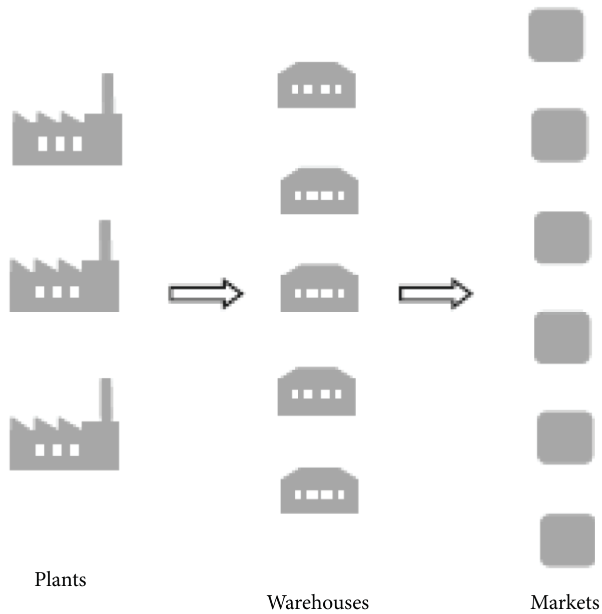

Figure 2: The structure of the supply chain considered by this research.

3. Research Method

In the problem under study in this research, there will be a three-stage supply chain. The first stage involves suppliers, the second stage involves product transportation, and the third stage involves a company manufacturing the final products. The transportation consists of several vehicles that have different speeds and capacities to transport products. This problem has several objectives, which include allocating the tasks to suppliers and vehicles so that they are delivered to the manufacturer as soon as possible. It is shown that the complexity of this problem is NP-hard and, therefore, it is not possible to use exact methods to solve the problem in a reasonable time. To solve this problem, a gravitational search algorithm will be used, and the proposed algorithm will be compared with the random search method in the literature. Figure 2 shows the structure of the supply chain considered by this research.

Therefore, in this section of the research, the research modeling method and its details, which include notation, equations of objective functions, and constraints, as well as parameters and variables of the research, are introduced. Also, the solution approach, which includes the gravitational search meta-heuristic algorithm and the settings related to its implementation, is explained.

3.1. Mathematical Model of the Problem. In this part of the research, the main components of the developed mathematical model, including notation of indices, parameters, variables, objective functions, and constraints, are introduced.

3.1.1. Notation. In Table 1, are shown the indices, parameters, and variables of the model.

3.1.2. Objective Functions

(i) Objective function of quality

The objective function of quality of the product that is sent from the $i-th$ manufacturer to the $j-th$ distributor. This objective function will occur in the loop of manufacturers, so that

$$\sum_{i=1}^{m}\sum_{j=1}^{n} Q_i X_{ij} = Z_1. \tag{1}$$

The goal of manufacturers is to maximize this objective function so that they can provide quality products to distributors and ultimately customers.

(ii) Objective function of total cost

The objective function of total cost is calculated from the sum of costs of transportation, maintenance, and fines for returned products.

(a) Transportation cost: the objective function of transportation cost from the $i-th$ manufacturer to the $j-th$ distributor. This objective function will occur between the manufacturer-distributor loops. So that

$$\sum_{i=1}^{m}\sum_{j=1}^{n} T_{ij}\left(\frac{X_{ij}}{V_i}\right). \tag{2}$$

From the point of view of manufacturers, the goal is to minimize this function to be able to decrease transportation costs.

(b) Maintenance cost: the objective function of the maintenance cost of the product sent by the $i-th$ manufacturer to the warehouse of the $j-th$ distributor. This objective function will occur in the loop of distributors. So that

$$\sum_{i=1}^{m}\sum_{j=1}^{n} H_j\left(\frac{X_{ij}}{2}\right). \tag{3}$$

From the point of view of distributors, the goal is to minimize this objective function to reduce the cost of maintaining the products in their warehouses.

(c) Cost of fine for returned products: the fuzzy objective function of fine for the returned products will be paid by the $j-th$ distributor to the $k-th$ customer. This objective function will occur between the customer-distributor circles. So that

$$\sum_{i=1}^{m}\sum_{j=1}^{n} P_{jk}\left(\tilde{\beta}_{jk} y_{jk}\right). \tag{4}$$

In this study, it is assumed that the fine paid by the $j-th$ distributor to the $k-th$ customer for each defective unit of products, which is equal to π percent of the price received by the $j-th$ distributor from the $k-th$ customer. With the definition of (S_{jk}) that is considered for the sale

Table 1: Symbolization.

Notation	Symbol	Description
Indices	i	Manufacturer number
	j	Distributor number
	m	Number of manufacturers
	n	Number of distributors
Parameters	X_{ij}	Volume of product produced by the $i-th$ manufacturer that is sent to the $j-th$ distributor
	Q_i	Quality of product produced by the $i-th$ manufacturer
	T_{ij}	Transportation cost for the number of times the produced product is sent from the manufacturer = transportation cost for the number of times the produced product is sent from the $i-th$ manufacturer to the $j-th$ distributor
	V_i	Shipping capacity of transportation vehicles that are sent from the warehouse of the $i-th$ manufacturer to the warehouse of distribution centers
	H_j	Cost of maintaining each unit of product in the warehouse of the $j-th$ distributor
	P_{jk}	The fine paid for each defective (returned) product by the $j-th$ distributor to the $k-th$ customer
	y_{jk}	The amount of the $k-th$ customer's demand that will be issued for the $j-th$ distribution center
	V_j	Shipping capacity of the transportation vehicles that are sent to the customers from the warehouse of the $j-th$ distributor
	S_{jk}	The sale price of each unit of product by the $j-th$ distributor to the $k-th$ customer
	X_i	The maximum amount of production that will be sent by the $i-th$ manufacturer to all distribution centers
Variables	$\tilde{\beta}_{jk}$	Fuzzy variable, a percentage of products sold by the $j-th$ distributor to the $k-th$ customer that is returned by the customer for reasons such as defective product
	$\tilde{St}_{jk}$	Fuzzy variables, duration of delivery of products from the $j-th$ distribution centers to the $k-th$ customer
	$\tilde{Y}_j$	Fuzzy variable, the minimum number of demands issued by all customers for the $j-th$ distribution center

of products, it is assumed $P_{jk} = \pi S_{jk}$. In general, it is assumed that the prime costs are different from the $i-th$ manufacturer to the k-th customer, in which case the sale price will be different from the $j-th$ distributor to the $k-th$ customer. In this problem, those customers who demand the purchase of a large volume of the manufactured product and are considered the most loyal and profitable customers of the SC system are called "effective customers," so that the behavior of such customers affects the planning of the whole system. Therefore, the objective function of the total cost of SC will be as follows:

$$\tilde{Z}_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} T_{ij}\left(\frac{X_{ij}}{V_i}\right) + \sum_{i=1}^{m}\sum_{j=1}^{n} H_j\left(\frac{X_{ij}}{2}\right) + \sum_{i=1}^{m}\sum_{j=1}^{l} P_{jk}\left(\tilde{\beta}_{jk} y_{jk}\right). \tag{5}$$

(iii) Objective function of delivery time

The fuzzy objective function of delivery time from the $j-th$ distributor to the $k-th$ customer. This objective function will occur between distributor-customer loops. So that

$$\tilde{Z}_3 = \sum_{j=1}^{n}\sum_{j=1}^{l} \tilde{St}_{jk}\left(\frac{y_{jk}}{V_j}\right). \tag{6}$$

In the real world, there are many factors that makes it impossible to certainly determine the delivery time of products from the $j-th$ distributor to the $k-th$ customer. It includes customer deployment, relocation of customer location, type of means of transportation (in terms of speed of transportation), change in policies, and chain management strategies for insourcing or outsourcing of transportation systems, etc. were mentioned. Therefore, in this objective function, the delivery time of products from the $j-th$ distribution center to the $k-th$ customer is considered a fuzzy variable.

This objective function is in stark contrast to the objective function Z_2. Because manufacturers tend to decrease delivery costs from a transportation system they have. While this will lead to increased delivery time for distributors' orders and can affect the response time to customer demand. Therefore, from the point of view of distributors, the goal is to minimize the time of sending products to customers because the shorter the time to respond to customer demand, the higher the level of service provided to customer demand will be, and it will ultimately bring the level of customer satisfaction.

(iv) Objective function of revenue

The objective function of revenue is from the sale of products by the $j-th$ distributor to the $k-th$ customer. This objective function will occur between distributor-customer loops. So that

$$\sum_{j=1}^{n}\sum_{k=1}^{l} S_{jk} y_{jk} = Z_4. \tag{7}$$

One of the most important objectives of a SC is to earn more revenue by selling products to customers. Therefore, this above-mentioned objective function must be maximized.

3.1.3. Constraints of the Problem

Constraints of lack of shortage

In order for manufacturers to be able to meet the number of orders issued by distributors in a timely manner, the following constraint is considered:

$$\sum_{i=1}^{m} X_{ij} = \sum_{k=1}^{l} y_{jk} \, (j = 1, 2, \ldots, n). \tag{8}$$

These constraints guarantee that the amount of production is such that in addition to decreasing maintenance costs in the warehouses of manufacturing and distribution centers, customer demand is also met on time and there is no shortage. Meeting customer demands in a timely manner can lead to the growth and credibility of the system.

(ii) Constraint of maximum capacity by the $i-th$ manufacturer

$$\sum_{j=1}^{n} X_{ij} \leq X_i \, (i = 1, 2, 3, \ldots m). \tag{9}$$

These constraints will guarantee that manufacturers present and implement effective programs for advertising and marketing their products so that they can gain a larger share of the competitive market. Proper planning for advertising and marketing of products can lead to the growth and improvement of the system.

(iii) Fuzzy constraint of the minimum number of demands issued to the $j-th$ distributor.

$$\sum_{k=1}^{l} Y_{jk} \geq \widetilde{Y}_j \, (j = 1, 2, 3, \ldots n). \tag{10}$$

One of the most important parts of SCM is determining and identifying potential customers and maintaining relationships with effective customer. These constraints are very important for the system because knowing the amount of customer demand can affect the future planning of the system. There are many factors that make it impossible to certainly determine the minimum number of customer demands. These include seasonal changes in demand, how to provide after-sales services, how to advertise and market products, persuading customers or business incentives, type of product quality, the emergence of cheaper and quality products by competitors, product obsolescence, price change policies, etc. Therefore, within the model constraints, the minimum number of demands issued by the $k-th$ customer to the $j-th$ distributor is considered a fuzzy variable.

3.2. Solution Approach: Gravitational Search Algorithm. The gravitational algorithm, or local search, is a new algorithm which, as its name implies, is a heuristic local search method. Moreover, this algorithm belongs to the group of methods that mimic some natural or physical processes (such as simulated annealing and genetic algorithms) [23]. In the gravitational algorithm, search space is thought of as a galaxy, and the solutions in search space are like objects inside a galaxy. For each of these objects exerts a reciprocal force. To obtain this force, Newton's law of gravity is used with a slight modification for the problems. According to the formula, this force is equal to the difference between the value of the candidate's response evaluation function and the current response divided by the neighborhood radius to the exponent of two. Since the high speed of the gravitational search algorithm is due to local search, creating, and selecting neighborhoods as well as choosing the right conditions for solutions to be neighbors in this algorithm are of great importance. In addition to high speed in achieving the optimal solution, the algorithm avoids reaching and staying in a local optimal due to the intrinsic properties of gravity [24].

3.2.1. Gravitational Search Algorithm Implementation Settings. The gravitational search algorithm has seven steps, which are as follows:

Step 1. Defining the information:

In this step, the desired information must be defined and the desired values must be assigned to them.

Step 2. Calling the information:

In this step, we have to call the data file that we have created to the algorithm and then, ask the algorithm to use the data that we have already defined and put into the structure of the algorithm for calculations.

Step 3. Defining the parameters:

In this step, all the parameters required to define the problem are defined. All the required parameters are as follows:

Matrix T_{ij} = Transportation cost of each shipment from the warehouse of i-th manufacturer to the warehouse of the j-th distributor.

Matrix H_{ij} = The cost of maintaining each unit of product produced by the $i-th$ manufacturer in the warehouse of the j-th distributor.

Matrix ST_{jk} = The determined time for each shipment of products from the warehouse of the j-th distributor to the k-th customer's location.

Matrix S_{jk} = Sale price of each unit of product in the j-th distributor to the k-th customer.

Matrix P_{jk} = The fine paid by the $i-th$ distributor to the $k-th$ customer for each unit of the returned product.

Matrix $\widetilde{\beta}_{jk}$ = Determined percentage of return on products sold by the $j-th$ distributor to the $k-th$ customer.

Matrix Y_j = The minimum number of products that customers demand to buy from distribution centers under fuzzy environment.

Matrix X_i = The maximum number of products that manufacturers can produce.

Matrix V_j = Shipping capacity of the transportation vehicles used by distribution centers.

Matrix V_i = Shipping capacity of the transportation vehicles used by the manufacturing centers.

nsol = The number of planets

T = the maximum number of iterations of the main loop ($T = 100$), the value of T is calculated based on trial and error.

G_0 = Constant coefficient of gravitational force.

Alpha = Radius of motion.

nbest = Each object can move towards n planets better than itself, which is ($n = 3$) here.

Step 4. Generating the population:

Once the parameters have been determined, it is time to generate the population. In the gravitational search algorithm, as in other evolutionary optimization methods, it starts with a number of initial populations. In this step, the population P_0 is generated randomly.

Step 5. Generating random answers:

In this step, we have to generate random answers for the number of planets, which is equal to 30. Thus, we first consider an empty vector whose variables include X, Y, objective function, information on the problem, motion velocity, mass, and gravitational force. Then, we iterate this external vector as many times as we need. For the number of solutions, we generate the initial answer randomly. All the numbers we have given randomly are between 0 and 1. Initially, the velocities of X and Y are zero. Since we have two variables, we must have velocity and gravitational force for the number of variables. Now, we have to find the best answer among the existing solutions. We call the obtained answer a global solution (g sol). It should be noted that since our objective function is maximization and the default of all algorithms is minimization, to solve this problem, we must multiply the objective function by a negative and, finally, multiply the number obtained by a negative again to return to the original state.

Step 6. Calculating the gravitational force on each planet:

In this step, we calculate the force that is exerted on mass i at time t by mass j to dimension d using the following formula:

$$F_{ij}^{d}(t) = G(t)\frac{M_i(t) \times M_j(t)}{R_{ij}(t) + \varepsilon}\left(X_j^d(t) - X_i^d(t)\right), \qquad (11)$$

where, $F_{ij}^{d}(t)$ = The force exerted on mass i at time t by mass j to dimension d, $G(t)$ = Constant of gravity at time t, $M_i(t)$ = Passive gravitational mass, $M_j(t)$ = Active gravitational mass, and $R_{ij}(t) + \varepsilon$ = Euclidean distance between two masses i and j.

Step 7. Performing the movement of the planets:

In this step, we move the planets and then minimize the sols. If the obtained answer is better than the global sol, we need to update the global sol. The main loop of the algorithm continues until the stopping condition is established. In our problem, the stopping condition is the number of iterations and its value is ($t = 100$).

4. Results

In this research, consider four objectives for the problem. For this purpose, multi-objective algorithms of gravitational search algorithms have been used. In the answer structure, we have planet X, planet Y, variable velocity X, variable velocity Y, optimization model, and mass, each of which will be explained separately. Planet X numbers are randomly defined in a 3×2 matrix. The numbers are then normalized so that the numbers obtained in the constraints apply. Therefore, in this section, we seek to satisfy the following constraint:

$$\sum_{j=1}^{n} X_{ij} \le X_i\,(i = 1, 2, 3, \ldots m). \qquad (12)$$

Planet Y numbers are randomly defined in a 4×3 matrix. The numbers are then normalized so that the numbers obtained in the constraint apply. Therefore, in this section, we seek to satisfy the following constraint:

$$\sum_{k=1}^{l} Y_{jk} \ge \widetilde{Y}_j\,(j = 1, 2, 3, \ldots n). \qquad (13)$$

Then, considering the above, we investigate the optimization model. The required information must be called first. Then, we obtain X, Y, and sols. Tables 1–3 show the results obtained from the values of the variables β_{jk}, st_{jk}, and Y_j.

Table 2 shows β_{jk} which, is the percentage of products sold by the j-th distributor to the k-th customer.

According to the percentage of products sold by each distributor to each customer, the share of products sold by each distributor to each customer is determined. Furthermore, it is determined how much of his/her expected product each customer has purchased in total of products purchased from each distributor. Based on the obtained values, the first customer has the lowest percentage of products purchased from the distributor, and the second customer has the highest percentage of products purchased from the distributor.

Also, Table 3 shows the delivery time of products from distribution centers to the customer. Table 3 shows how long it takes for each product to be delivered from the distribution centers to the customer.

Moreover, Table 4 shows the minimum number of demands issued by all customers for the $j - th$ distribution centers.

Table 2: Optimal value of β_{jk}.

J	K				
	$K=1$	$K=2$	$K=3$	$K=4$	Total percentage sold (customer)
$J=1$	20	25	30	25	100
$J=2$	15	35	25	25	100
$J=3$	10	40	30	20	100
Total percentage sold (customer)	45	100	85	70	

Table 3: Optimal value of St_{jk} (days).

j	K			
	$K=1$	$K=2$	$K=3$	$K=4$
$J=1$	15	30	29	15
$J=2$	10	25	26	10
$J=3$	15	55	35	15

Table 4: Optimal value of Y_j.

J	K			
	$K=1$	$K=2$	$K=3$	$K=4$
$J=1$	1500	750	1000	750
$J=2$	2000	1250	1200	550
$J=3$	1000	3500	1500	1200

Table 5: Optimal answer of objective functions.

Objective function	Objective function 1	Objective function 2	Objective function 3	Objective function 4
Value	12	1580	15	2200

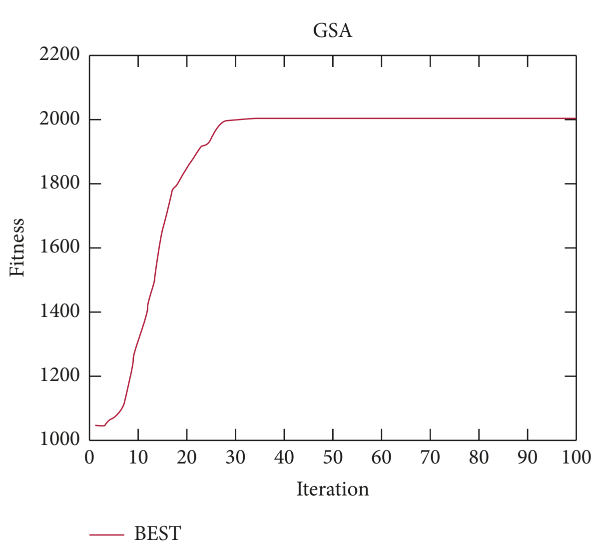

Figure 3: The value of the combined objective function for various iterations.

By determining the optimal values of the variables, the optimal values of the four-objective functions considered are calculated according to Table 5.

Now, the combined final objective function can be calculated according to the satisfied constraints and objectives. Figure 3 shows the optimal value of the combined function from the four functions considered for various iterations. As shown in Figure 3, from iteration 30 onwards, the value of the combined objective function reaches a stable value close to the optimal 2000 [25].

5. Conclusion

Supply chain management is defined as designing, planning, implementing, controlling, and monitoring supply chain activities with the aim of creating net value, creating competitive infrastructure, using procurement worldwide, coordinating supply with demand, and measuring performance globally. Given the growing concerns about the failure of businesses, considering various aspects of a supply chain has become a trend among experts. Hence, a channel selection system for transportation planning in the supply chain is introduced in this research. This system can be used as part of a set of supply chain planning systems and can help managers effectively solve logistics problems. This system can be used as part of the set of supply chain planning systems and helps managers effectively solve logistics problems. The valuable knowledge that the results of this research can add to the managers is that it is possible to determine the amount of the customer's unknown demand from the distribution center using the proposed framework, determine the product delivery time from the distributor to the customer, and also determine the percentage of returned products. Specify the defective one that was sold by the distributor to the customer. Due to the fact that transportation planning has different characteristics in different industries, the most important contribution of this research is to provide a framework for structured classification of this problem. Also, while providing the design and optimization approach of this system, the characteristics of the model components and how the optimization algorithm relates to the model will be explained. Then, the problem will be solved using a hybrid evolutionary algorithm based on the gravitational search algorithm. Based on the results, in addition to determining the optimal value of the objective functions separately, a near-optimal value for the combined objective function is obtained during different iterations. Also, the percentage of products sold by the distributor to the customer, the delivery time of the products from the distribution centers to the customer, and the minimum number of demands issued by the customer to the distribution centers, which are necessary to determine the value of the objective function, are also calculated. The development of the proposed model is provided as a multiperiod model as the most important suggestion that can be considered for future research.

Data Availability

The data are available upon reasonable request from the responsible author.

Disclosure

This manuscript has not been submitted to, nor is under review at another journal or other publishing venues and has not been self-plagiarised.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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