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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 meta-heuristic 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	*		*	*	*	*	*	*	*	*	*	*	*	*	*

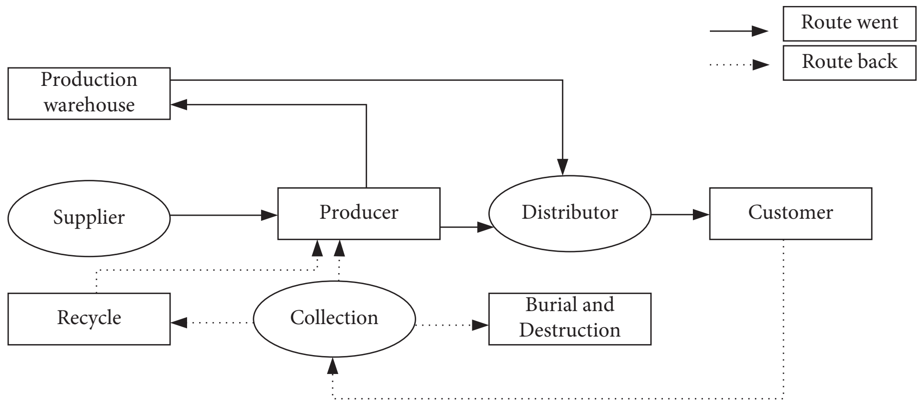

Figure 1: Proposed supply chain structure.

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.

$f'o_{cs}$ 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

$$\min z1 = \left(\sum_{d\in D} h_d x_d + \sum_{g\in G} h_g' x_g + \sum_{b\in B} h_b'' x_b + \sum_{e\in E} h_e'' x_e\right) +,$$

$$+ pr_s \left(\sum_t \sum_s \left(\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} d^c_{nms} z^{ct}_{nms} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx^{st}_{jks} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d^c_{dl\ ,s} z^{ct}_{dls}\right.\right.$$

$$+ \sum_{s\in S}\sum_{t\in T}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^c_{\mathrm{lgs}} z^{ct}_{\mathrm{lgs}} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^c_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^c_{geqs} z^{ct}_{geqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^c_{gmqs} z^{ct}_{gmqs}\right.$$

$$\left. + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^c_{bmqs} z^{ct}_{bmqs}\right)$$

$$+ \sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} fo_{cs}.z^{ct}_{mds} + \sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} fo_{cs}' \left(\left(\sum_{g\in G}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{g\in G}\sum_{e\in E} z^{ct}_{geqs} + \sum_{g\in G}\sum_{m\in M} z^{ct}_{gmqs}\right)\right)$$

$$M\inf_2 = LM + LP,$$

$$LM = \sum_{b\in B} x_b.cb_b'' + \sum_{g\in G} x_g.cb_g' + \sum_{e\in E} x_e.cb_e'' + \sum_{d\in D} x_d.cb_d,$$

$$LP = \sum_{s\in S} w_{sen}.\sum_{t\in T} CEM\left[\sum_t\sum_s\left(\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} d^c_{nms} z^{ct}_{nms} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx^{st}_{jks} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d^c_{dl\ ,s} z^{ct}_{dls}\sum_{s\in S}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^c_{\mathrm{lgs}} z^{ct}_{\mathrm{lgs}}\right.\right.\right.$$

$$\left.\left.\left. + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^c_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^c_{geqs} z^{ct}_{geqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^c_{gmqs} z^{ct}_{gmqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^c_{bmqs} z^{ct}_{bmqs}\right)\right)\right]$$

$$M\inf 3 = \sum_{t\in T}\sum_{d\in D} pol_{dt}.x_d + \sum_{g\in G}\sum_{t\in T} pol_{gt}'.x_g + \sum_{b\in B}\sum_{t\in T} pol_{bt}''.x_b + \sum_{e\in E}\sum_{t\in T} pol_{et}''.x_e,$$

$$\sum_{e\in E} x_e \geq 1,$$

$$\sum_{g\in G} x_g \geq 1,$$

$$\sum_{d\in D} x_d \geq 1,$$

$$\sum_{b\in B} x_b \geq 1,$$

$$\sum_{q_2}\sum_{n\in N} z^{ct}_{gbqs} = rr''^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lgqs}}\right)\forall g\in G, c\in C, t\in T, s\in S,$$

$$\sum_{g\in G} z^{ct}_{\mathrm{lgqs}} = r^c_{lqs}.\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls}\forall l\in L, d\in D, t\in T, q\in Q, s\in S,$$

$$\sum_{q1}\sum_{m\in M} z^{ct}_{gmqs} = rr^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lgqs}}\right)\forall g\in G, c\in C, t\in T, s\in S,$$

$$\sum_{m\in M}\left(z^{ct}_{mds} + w^{ct}_{mds}\right) = \sum_{l\in L} z^{ct}_{dls}\forall d\in D, c\in C, t\in T, s\in S,$$

$$\sum_{q2}\sum_{e\in E} z^{ct}_{geqs} = rr'^{ct}\sum_q\left(\sum_{l\in L} z^{ct}_{\mathrm{lgqs}}\right)\forall c\in C, t\in T, g\in G, s\in S,$$

$$\sum_{q_2}\sum_{g\in G} z^{ct}_{gbqs} = \sum_q\sum_{m\in M} z^{ct}_{bmqs}\forall b\in B, c\in C, t\in T, s\in S,$$

$$\sum_{q_1}\sum_{m\in M} z^{ct}_{gmqs} + \sum_{q_2}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{q_3}\sum_{e\in E} z^{ct}_{geqs}, = \sum_{q}\sum_{l\in L} z^{ct}_{\mathrm{l}gqs},$$

$$\sum_{n\in N} z^{ct}_{nms} + \sum_{q_1}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q\in Q}\sum_{b\in B} z^{ct}_{bmqs},$$

$$= \sum_{d\in D} z^{ct}_{mds} \forall m \in M, c \in C, t \in T, s \in S,$$

$$\sum_{d\in D} z^{ct}_{dls} = d^{ct}_{ls} \forall l \in L, c \in C, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{m\in M} z^{ct}_{nms} \le li_n \forall n \in N, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{c\in C}\sum_{d\in D} z^{ct}_{mds} \le li_m \forall m \in M, t \in T, s \in S,$$

$$\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls} \le li_d x_d \forall d \in D, t \in T, s \in S,$$

$$\sum_{q_3}\sum_{c\in C}\sum_{g\in G} z^{ct}_{geqs} \le li_e x_e \forall e \in E, t \in T, s \in S,$$

$$\sum_{c\in C}\left(\sum_{q_1}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q}\sum_{b\in B} z^{ct}_{bmqs}\right) \le li'_m \forall m \in M, t \in T, s \in S,$$

$$\sum_{qs_1}\sum_{c\in C}\sum_{g\in G} z^{ct}_{gbqs} \le li_b x_b \forall b \in B, t \in T, s \in S,$$

$$\sum_{q_1}\sum_{c\in C}\sum_{g\in G} z^{ct}_{gmqs} + \sum_{q_3}\sum_{c\in C}\sum_{e\in E} z^{ct}_{geqs} + \sum_{q_2}\sum_{c\in C}\sum_{b\in B} z^{ct}_{gbqs} \le li_g x_g$$

$$x_d, x_g, x_p, x_e \in \{1, 0\} \forall d \in D, g \in G, b \in B, e \in E,$$

$$z^{ct}_{gmqs}, z^{ct}_{mds}, z^{ct}_{dls}, z^{ct}_{bmqs}, z^{ct}_{mds}, z^{ct}_{\mathrm{l}gqs}, z^{ct}_{geqs}, z^{ct}_{nms}, z^{ct}_{gbqs} \ge 0. \tag{1}$$

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

d	g	b	e
1	1	0	0
0	0	1	1
1	1	0	1
0	1	1	1

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

Parent 1	23	65	54	55	100	42
	42	85	19	129	102	87
	54	64	13	410	164	120
	421	413	88	200	321	18
Parent 2	11	36	37	28	13	59
	73	64	18	100	95	36
	48	46	77	205	87	93
	214	74	39	45	67	45
Child 1	23	65	37	28	100	42
	42	85	18	100	102	87
	54	64	77	205	164	120
	421	413	39	45	321	18
Child 2	11	36	54	55	13	59
	73	64	19	129	95	36
	48	46	13	410	87	93
	214	74	88	200	67	45

Figure 3: Two-point cross over.

Parent	18	45	64	26	17	84
	6	16	82	59	104	100
	74	44	75	104	164	57
	100	123	23	36	321	19
Child	18	45	64	26	17	74
	100	104	59	82	16	6
	74	44	75	104	164	57
	100	123	23	36	321	19

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

solutions; the method of calculating these metrics is given below as follows:

(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
$\mathbf{U} \sim [100, 200]$	$d^{c}_{gmqs}, d^{c}_{nms}, d^{c}_{mds}, d^{c}_{\mathrm{lgs}}$	$U \sim [2000, 3000$	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

$$\mathrm{MID} = \frac{\sum_{i=1}^{n} \sqrt{\left(f_{1i} - f_{1}^{\mathrm{best}}/f_{1,\mathrm{total}}^{\max} - f_{1,\mathrm{total}}^{\min}\right)^{2} + \left(f_{2i} - f_{2}^{\mathrm{best}}/f_{2,\mathrm{toal}}^{\max} - f_{2,\mathrm{total}}^{\min}\right)^{2}}}{n}. \quad (2)$$

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:

$$\mathrm{SM} = \frac{\sqrt{\sum_{i=1}^{n} \left(d_{i} - \overline{d}\right)^{2}/n}}{\overline{\mathrm{d}}}. \quad (3)$$

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

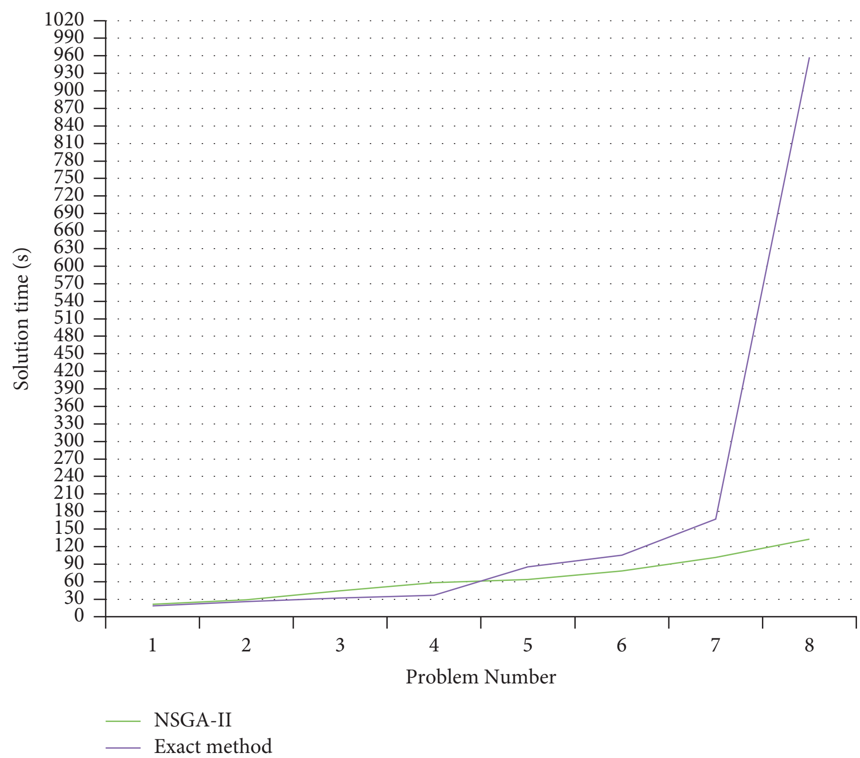

Figure 5: Solving time of numerical examples.

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.

Table 6: Capacity parameter.

Centers	Capacity
Center 1	1000
Center 2	1500
Center 3	2000
Center 4	1000
Center 5	1000

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 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

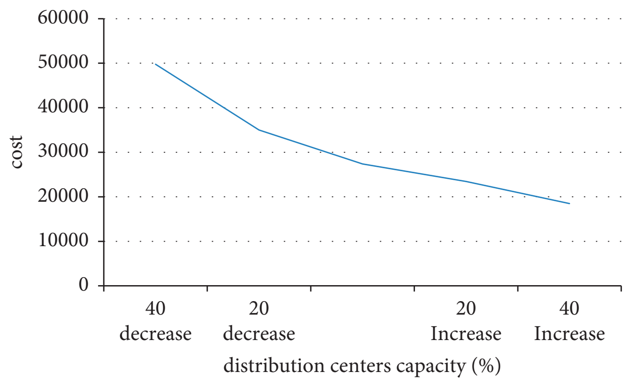

Figure 6: Sensitivity analysis of the objective function relative to the capacity of distribution centers.

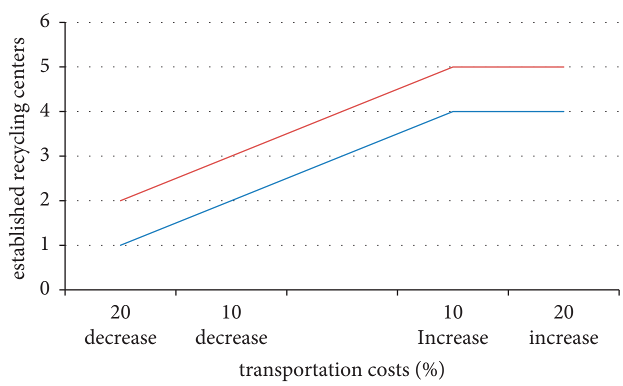

Figure 7: Sensitivity analysis of the number of established recycling centers relative to transportation costs.

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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