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Research Article

Resilient Supply Chain Planning for the Perishable Products under Different Uncertainty

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In this research, the perishable products' closed-loop supply chain network design problem is assessed by considering the disruption in production and distribution capacity and taking into account the uncertainty in customer demand. The main contribution of this research is modeling perishable products' supply chain optimization and providing intelligent solution methods. In this regard, a mixed-integer mathematical model is proposed. This mathematical model consists of three objective functions. The first objective function is related to profit maximization, the second objective function is to minimize delivery time, and the third objective function is to reduce lost business days. Moreover, non-dominated sorting genetic algorithm II (NSGAII) and Multi-Objective Evolutionary Algorithm (MOEA) have been applied to optimize the proposed model. The research results show that the proposed meta-heuristic algorithm can provide a complete set of Pareto solutions in a reasonable amount of time. Moreover, based on different criteria, MOEA provides the non-dominated solutions with a higher quality, while NSGAII presents the Pareto boundary with more solutions than MOEA.

1. Introduction

Supply chain network design (SCND) for any industry or business means achieving a satisfactory framework that includes all elements such as product, market, process, technology, cost, external environment, and their factors and their impact, along with evaluating different scenarios. An unexpected disruption may occur in any activity performed by a supply chain. Incidents such as floods, earthquakes, hurricanes, fires, staff strikes, and transportation delays are possible supply chain disruptions. Moreover, disruptions can result from efforts to create a more efficient and cost-effective supply chain environment [1, 2].

What is important is that any breakdown or disruption in each node of a supply chain can have significant adverse operational and financial effects on the entire designed network structure and even cause the entire supply chain network to fail. To reduce the risks of unexpected disruptions, supply chains should be designed to deal with these unexpected events, provide an efficient and effective response, and move to a more robust state after disruptions [3].

A resilient supply chain is a system that has the ability to recover quickly from disruptions and ensures that customers are minimally damaged. In addition to resilience, supply chain sustainability has also received considerable attention in recent decades in academia and global organizations [4–6]. Due to the pressures of various stakeholders, especially government legislators, NGOs, community activists, and global competition, many companies have a certain amount of commitment to sustainability measures. The goal of a sustainable supply chain is to create, manage, protect, and enhance economic, social, and environmental values over the life of goods or services of organizations and companies [7, 8].

This section will review some of the most important and relevant articles in the two areas of sustainability and resilience. One of the most important research items that simultaneously consider the dimensions of stability and resilience in the designed mathematical model is the study of Zahiri et al. [9]. They proposed a multi-objective linear programming model for designing a sustainable and resilient drug supply chain network under uncertainty. Moreover, they developed a fuzzy possibility programming approach for their model and used a new meta-heuristic algorithm to solve it.

Jabbarzadeh et al. [10] assessed a novel approach based on a stochastic programming approach to formulating a multi-objective mathematical model for roust and resilient SCND. They evaluated their mathematical model in the plastic pipe industry.

Other research items in the field of SCND disorders include Torabi et al. [11]. They proposed a mixed-integer linear programming model for the design of a closed-loop SCND, taking into account facility disruption and input data uncertainty with the aim of minimizing total costs. Moreover, a feasible and robust planning approach has been applied to solve this model.

Chaabane et al. [12] proposed a multi-objective linear planning model considering important aspects of sustainable SCND and strategic planning. This model links the carbon emission business plan to achieving sustainability goals in a cost-effective way that controls greenhouse gases and recycles products at the end of their life. Fathollahi-Fard et al. [13] proposed a two-stage multi-objective stochastic programming model with social considerations for closed-loop SCND. The two social dimensions considered in this model are job opportunities and job injuries, and they have used a hybrid meta-heuristic algorithm approach to solve the model.

Hasani et al. [14] designed a nonlinear mixed-integer model for SCND under uncertainty. They proposed several strategies for reducing the risk of the supply chain. Moreover, to solve the model, they developed a Taguchi-based parallel memetic algorithm and used the innovative Lagrange relaxation approach to evaluate the quality of the solutions and the effectiveness of the proposed algorithm.

Yavari et al. [15] designed a green and flexible closed-loop SCND for perishable products, taking into account the disruption of the power distribution network. To mitigate the risks of this disruption, they proposed merging the two supply chain networks and electricity as a strategy. For this purpose, a dependent two-layer network was designed by using a mixed linear programming model. Liu et al. [16] proposed an integrated model for sustainable supply chain management by considering perishable products. In this research, the YALMIP toolbox was used to solve the model, and the optimal solution to this complex multi-objective problem was obtained. Tsao et al. [17] assessed the supply chain network design for perishable products by considering the credit for trades throughout the supply chain. In this regard, they proposed a convex objective function and solved it for the fresh food case study. Abbas et al. [18] investigated the effect of the environment on the quality of perishable products in different supply chains. In this research, simulation optimization was implemented to measure the probability of time-saving for the quality of perishable products from environmental effects and their influences on product demand.

After careful consideration of the most important research items in the literature, the contribution of this research can be summarized as follows:

(1) Proposing a mixed-integer programming model for planning a closed-loop supply chain of perishable products.

(2) Optimizing the total delivery time as a novel objective function with economic and social objectives simultaneously.

(3) Proposing MOEA and NSGAII as two efficient multi-objective meta-heuristic algorithms to optimize the proposed model.

The rest of the paper is organized as follows: The problem statement is presented in Section 2. The proposed algorithms are illustrated in Section 3. The comprehensive numerical results are depicted in Section 4. Finally, the research is concluded in Section 5.

2. Problem Statement

In this paper, a closed-loop supply chain network is designed in a multi-product and multi-period mathematical model. This supply chain includes suppliers, production centers, distributors, and customers in forward flow and collection, disposal, and recycling centers in reverse flow. In this supply chain, production centers are also used as recycling centers. Several transportation systems (TS) are available to send the products throughout the supply chain. These transportation systems are different in terms of cost and delivery time, as well as the amount of emissions, and supply chain management must choose the most appropriate ones in terms of economy and agility.

The reason for choosing several transportation systems in the supply chain network is that different transportation vehicles can always be used for perishable products. At the same time, due to the perishability of the product, the time and quality of transportation are very critical. Therefore, it is necessary for supply chain managers to make decisions about their transportation systems. Accordingly, in this research, in addition to the design of the supply chain network, the type of transportation system at each echelon of the supply chain is specified.

In addition, each of the established production centers must have a specific type of technology. In other words, supply chain management also seeks to decide on the technology level of each production unit. Moreover, in order to consider supply chain disruption, it is assumed that in each period, a percentage of the capacity of production centers and distribution centers is disrupted and cannot be used, and the supply chain must be prepared to face these disruptions.

In the real world, not all supply chain parameters are definite. Therefore, in this research, customers' demand is considered an uncertain parameter under different scenarios. The supply chain under study is also a sustainable supply chain whose three general principles, namely, economic, social, and environmental, are considered in the mathematical model. In the economic dimension, maximizing the profit of the entire supply chain is considered. Socially, the reduction of days lost due to workers' injuries is intended. From an environmental point of view, all pollutants from production and distribution are calculated, and it is guaranteed that this amount is less than the maximum allowed. (Tables 1 and 2).

2.1. Mathematical Model

2.1.1. Sets. 2.2. Parameters. 2.3. Objective Functions and Constraints.

$$\text{Max} f1 = \sum_t \text{Income}_t - \text{Cost}_t, \tag{1}$$

$$\text{Income}_t = \sum_j \sum_c \sum_p \sum_l \text{xjc}^t_{\text{jcpl}3\delta} sp^t_{cp}, \tag{2}$$

$$\begin{aligned}\text{Cost}_t = {} & \sum_i fi^t_{i\tau}\left(xi^t_{i\tau} - xi^{t-1}_{i\tau}\right) + \sum_j fj^t_j\left(xj^t_j - xj^{t-1}_j\right) + \sum_s fs^t_s xs^t_s \frac{1}{2} \\ & + \sum_\delta \rho_\delta \Bigg(\sum_s \sum_i \sum_r \sum_{l1} \text{xsi}^t_{\text{sirl}1\delta} pc^t_{sr} + \sum_j \sum_c \sum_p \sum_{l3} \text{xjc}^t_{\text{jcpl}3\delta} hc^t_{jp} + \sum_i \sum_j \sum_p \sum_{l2} \text{xij}^t_{\text{ijpl}2\delta} mc^t_{ip\tau} + \\ & + \sum_j \sum_p \text{INV}^t_{jp\delta} hc^t_{jp} + \sum_c \sum_m \sum_p \sum_{l4} \text{xcm}^t_{\text{cmpl}4\delta} oc^t_{mp} + \sum_m \sum_i \sum_p \sum_{l5} \text{xmi}^t_{\text{mipl}5\delta} rc^t_{ip} + \\ & + \sum_m \sum_n \sum_p \sum_{l6} \text{xmn}^t_{\text{mnpl}6\delta} nc^t_{np} - \sum_m \sum_i \sum_p \sum_{l5} \text{xmi}^t_{\text{mipl}5\delta} sc + \sum_s \sum_i \sum_r \sum_{l1} \text{xsi}^t_{\text{siprl}1\delta} \text{tcsi}^t_{\text{sirl}1} + \\ & + \sum_i \sum_j \sum_p \sum_{l2} \text{xij}^t_{\text{ijpl}2\delta} \text{tcij}^t_{\text{ijpl}2} \\ & + \sum_j \sum_c \sum_p \sum_{l3} \text{xjc}^t_{\text{jcpl}3\delta} \text{tjc}^t_{\text{jcpl}3} + \sum_c \sum_m \sum_p \sum_{l4} \text{xcm}^t_{\text{cmpl}4\delta} \text{tcm}^t_{\text{cmpl}4} + \sum_m \sum_i \sum_p \sum_{l5} \text{xmi}^t_{\text{mipl}5\delta} \text{tmi}^t_{\text{mipl}5} \\ & + \sum_m \sum_n \sum_p \sum_{l6} \text{xmn}^t_{\text{mnpl}6\delta} \text{tmn}^t_{\text{mnpl}6} + \sum_c \sum_p b^t_{cp\delta} \text{pen},\end{aligned} \tag{3}$$

$$\begin{aligned}\text{Min Total deliver time} = {} & \sum_s \sum_i \sum_r \sum_{l1} \sum_t A1^t_{\text{sil}1} \text{tsi}^t_{\text{sirl}1} + \sum_i \sum_j \sum_p \sum_{l2} \sum_t A2^t_{\text{ijl}2} \text{tij}^t_{\text{ijpl}2} + \\ & + \sum_j \sum_c \sum_p \sum_{l3} \sum_t A3^t_{\text{jcl}3} t\, jc^t_{\text{jcpl}3} + \sum_c \sum_m \sum_p \sum_{l4} \sum_t A4^t_{\text{cml}4} \text{tcm}^t_{\text{cmpl}3} \\ & + \sum_m \sum_i \sum_p \sum_{l5} \sum_t A5^t_{\text{mil}5} \text{tmi}^t_{\text{mipl}5} \\ & + \sum_m \sum_n \sum_p \sum_{l6} \sum_t A6^t_{\text{mnl}6} \text{tmn}^t_{\text{mnpl}6},\end{aligned} \tag{4}$$

$$\begin{aligned}\text{social responsibility} = {} & \sum_i \sum_\tau \sum_t xi^t_{i\tau} f\, ji^t_{i\tau} + \sum_j \sum_t xj^t_j \text{fjj}^t_j + \sum_j \sum_t xm^t_m \text{fjm}^t_m + \sum_j \sum_t xn^t_n f\, jn^t_n + \sum_i \sum_\tau \sum_t \frac{vi^t_{i\tau} xij^t_{ijpl2\delta}}{ci^t_i} \\ & \sum_i \sum_j \sum_p \sum_{l2} \sum_t \frac{\text{vjj}^t_j \text{xij}^t_{\text{ijpl}2\delta}}{ci^t_j} + \sum_c \sum_m \sum_p \sum_{l3} \sum_t \frac{vjm^t_j xcm^t_{cmpl4\delta}}{cm^t_m} + \sum_m \sum_n \sum_p \sum_{l6} \sum_t \frac{vjn^t_j xmn^t_{mnpl6\delta}}{cn^t_n}\end{aligned} \tag{5}$$

s.t:

$$\sum_j \sum_{l3} xjc^t_{jcpl3\delta} + b^t_{cp\delta} \geq dm^t_{cp\delta} \quad \forall c, p, t, \delta, \tag{6}$$

$$\sum_j \sum_p \sum_{l2} cr_{cp} xij^t_{ijpl2\delta} = \sum_s \sum_{l1} xsi^t_{sirl1\delta} + \sum_m \sum_p \sum_{l5} cr_{rp} xmi^t_{mipl5\delta} \quad \forall i, p, t, \delta, \tag{7}$$

$$INV^{t-1}_{jp\delta} + \sum_{i}\sum_{l2} xij^{t}_{ijpl2\delta} = INV^{t}_{jp\delta} + \sum_{c}\sum_{l3} xjc^{t}_{jcpl3\delta} \quad \forall j, p, \delta, \tag{8}$$

$$\sum_{m}\sum_{p}\sum_{l4} xcm^{t}_{cmpl4\delta} = \gamma_m \sum_{j}\sum_{p}\sum_{l3} xjc^{t}_{jcpl3\delta} \quad \forall c, t, \delta, \tag{9}$$

$$\sum_{i}\sum_{p}\sum_{l5} xmi^{t}_{mipl5\delta} = \gamma_i \sum_{c}\sum_{p}\sum_{l4} xcm^{t}_{cmpl4\delta} \quad \forall m, t, \delta, \tag{10}$$

$$\sum_{n}\sum_{p}\sum_{l6} xmn^{t}_{mnpl6\delta} = \gamma_n \sum_{c}\sum_{p}\sum_{l4} xcm^{t}_{cmpl4\delta} \quad \forall m, t, \delta, \tag{11}$$

$$\sum_{\tau} xi^{t}_{i\tau} \le 1 \quad \forall i.t, \tag{12}$$

$$\sum_{j}\sum_{p}\sum_{l2} xij^{t}_{ijpl2\delta} \le \left(1 - px^{t}_{i\tau}\right) ci^{t}_{i} xi^{t}_{i\tau} \quad \forall i, t, \tau, \delta, \tag{13}$$

$$\sum_{i}\sum_{r}\sum_{l1} xsi^{t}_{sirl1\delta} \le CS^{t}_{sr} \quad \forall s.r.\tau.\delta, \tag{14}$$

$$\sum_{p} INV^{t}_{jp\delta} + \sum_{c}\sum_{p}\sum_{l3} xjc^{t}_{jcpl3\delta} \le \left(1 - pj^{t}_{j}\right) cj^{t}_{j} xj^{t}_{j} \quad \forall j.t.\delta, \tag{15}$$

$$\sum_{c}\sum_{p}\sum_{l4} xcm^{t}_{cmpl4\delta} \le cm^{t}_{m} \quad \forall m.t.\delta, \tag{16}$$

$$\sum_{c}\sum_{p}\sum_{l5} xmi^{t}_{mipl5\delta} \le cr^{t}_{i} \quad \forall i.t.\delta, \tag{17}$$

$$\begin{aligned} &\sum_{i}\sum_{j}\sum_{p}\sum_{l2} xij^{t}_{ijpl2\delta}\left(etij^{t}_{ijpl2} + em^{t}_{pir}\right) + \sum_{j}\sum_{c}\sum_{p}\sum_{l3} xjc^{t}_{jcpl3\delta} etjc^{t}_{jcpl3} \\ &\sum_{j}\sum_{c}\sum_{p}\sum_{l3} xsi^{t}_{sirl1\delta} etsi^{t}_{sirl1} + \sum_{c}\sum_{m}\sum_{p}\sum_{l4} xcm^{t}_{cmpl4\delta} etcm^{t}_{cmpl4\delta} + \sum_{m}\sum_{i}\sum_{p}\sum_{l5} xmi^{t}_{mipl5\delta} etmi^{t}_{mipl5\delta} \\ &+ \sum_{m}\sum_{n}\sum_{p}\sum_{l6} xmn^{t}_{mnpl6\delta} etmn^{t}_{mnpl6\delta} \le emax^{t} \forall t, \delta, \end{aligned} \tag{18}$$

$$\sum_{l1} A1^{t}_{sil1} \le 1 \quad \forall s, i, t, \tag{19}$$

$$\sum_{l2} A2^{t}_{ijl2} \le 1 \quad \forall i, j, t, \tag{20}$$

$$\sum_{l3} A3^{t}_{jcl3} \le 1 \quad \forall j, c, t, \tag{21}$$

$$\sum_{l4} A4^{t}_{cml4} \le 1 \quad \forall m, c, t, \tag{22}$$

$$\sum_{l5} A5^{t}_{mil5} \le 1 \quad \forall m, i, t, \tag{23}$$

$$\sum_{l6} A6^{t}_{mnl6} \le 1 \quad \forall m, n, t, \tag{24}$$

$$A1^{t}_{sil1} \le \sum_{r} xsi^{t}_{sirl1\delta} \quad \forall s, i, l1, t, \delta, \tag{25}$$

$$A2^t_{ijl2} \leq \sum_p xij^t_{ijpl2\delta} \quad \forall i, j, l2, t, \delta, \tag{26}$$

$$A3^t_{jcl3} \leq \sum_p xjc^t_{jcpl3\delta} \quad \forall j, c, l3, t, \delta, \tag{27}$$

$$A5^t_{mil5} \leq \sum_p xcm^t_{jcpl4\delta} \quad \forall c, m, l4, t, \delta, \tag{28}$$

$$A5^t_{mil5} \leq \sum_p xmi^t_{mnpl6\delta} \quad \forall m, i, l5, t, \delta, \tag{29}$$

$$A6^t_{mnl6} \leq \sum_p xmn^t_{mnpl6\delta} \quad \forall m, n, l6, t, \delta, \tag{30}$$

$$\sum_r xsi^t_{sirl1\delta} \leq BM * A1^t_{sil1} \quad \forall s, i, l1, t, \delta, \tag{31}$$

$$\sum_p xij^t_{ijpl2\delta} \leq BM * A2^t_{ijl2} \quad \forall i, j, l2, t, \delta, \tag{32}$$

$$\sum_p xjc^t_{jcpl3\delta} \leq BM * A3^t_{jcl3} \quad \forall j, c, l3, t, \delta, \tag{33}$$

$$\sum_p xcm^t_{cmpl4\delta} \leq BM * A4^t_{cml4} \quad \forall c, m, l4, t, \delta, \tag{34}$$

$$\sum_p xmi^t_{mipl5\delta} \leq BM * A5^t_{mil5} \quad \forall m, i, l5, t, \delta, \tag{35}$$

$$\sum_p xmn^t_{mnpl6\delta} \leq BM \times A6^t_{mnl6} \quad \forall m, i, l6, t, \delta. \tag{36}$$

(1), or the function of the first objective, calculates the total profit which is obtained from the revenues and expenditures throughout the supply chain. In (2), one of the most important segments of the first objective is calculated, the total review obtained from selling the products. (3) Calculate the next important segment and provide the total costs of the supply chain, including the fixed and variable cost of facilities, costs of supply and purchase, production, inventory, distribution, and collecting. Constraint (4) minimizes the total delivery times of raw materials and products by selecting the type of transportation system. (5), or the third objective function, reduces the days lost due to work losses incurred during the establishment of the facility or during the manufacture, production, and maintenance of products.

Constraint (6) states that in each period, the total goods sent to customers and the extent of their shortage must be greater than or equal to their demand in the same period. Constraint (7) shows that the amount of raw material imported to each of the production centers in each period is equal to the amount of output from it in the same period.

Constraint (8) demonstrates the inventory balance in each distribution center based on the imports and exports from each of them. It guarantees the amount of distributed products. Constraints (9)–(11) show the flow of products and the balance between them in the reverse supply chain. Constraint (12) guarantees that each production center in each period can be constructed with only one type of technology. Constraints (13) and (15) express the limitations of material capacity in production centers and distribution centers. The category of disorder is included in these constraints. Constraints (14)–(17) indicate the capacity limit of the facility. Constraint (18) specifies the maximum permissible total pollution of production and distribution. Constraints (19) to (24) state that only one transportation system can be used in each member of the supply chain. Constraints (25) to (30) indicate that the transportation system is used between members of the supply chain who send goods to each other. Constraints (31) to (36) state that unrelated members should not send any products throughout the supply chain.

3. Solution Method

In order to optimize the proposed mathematical model, it is necessary to select some suitable solution methods. In this regard, exact solution methods cannot be effective, because the proposed mathematical model has several complex

Table 1: Sets of mathematical model.

s	Supplier Index $(s = 1, 2, \ldots, s)$.
i	Index related to production centers $(i = 1, 2, \ldots, I)$.
j	Index of distribution centers $(j = 1, 2, \ldots, J)$.
c	Customer index $(c = 1, 2, \ldots, C)$.
m	Index of potential locations for collection centers $(m = 1, 2, \ldots, M)$.
n	Index of potential centers for destruction of goods $(n = 1, 2, \ldots, N)$.
$l1$	Index for transportation systems of goods from suppliers to production centers $(l1 = 1, 2, \ldots, L1)$.
$l2$	Index related to goods transportation systems from production centers to distribution centers $(l2 = 1, 2, \ldots, L2)$.
$l3$	Index related to freight transportation systems from distribution centers to customers $(l3 = 1, 2, \ldots, L3)$.
$l4$	Index related to the transportation systems of goods from customers to collection centers $(l4 = 1, 2, \ldots, L4)$.
$l5$	Index related to freight transportation systems from collection centers to production centers $(l5 = 1, 2, \ldots, L5)$.
$l6$	Index of freight transportation systems from collection centers to disposal centers $(l6 = 1, 2, \ldots, L6)$.
p	Product index $(p = 1, 2, \ldots, P)$.
r	Raw materials index $(r = 1, 2, \ldots, R)$.
t	Index of time periods $(t = 1, 2, \ldots, T)$.
τ	Production technology index $(\tau = 1, 2, \ldots, \Pi)$.
δ	Scenario index $(\delta = 1, 2, \ldots, \Delta)$.

Table 2: Mathematical model parameters.

dm^t_{cps}	Customer demand c for product p in period t under scenario δ
pc^t_{sr}	Cost of purchasing a unit of raw material r from supplier s in period t
sp^t_{cp}	The selling price of each unit of product p to customer c in period t
$mc^t_{ip\tau}$	Unit of production cost of product p in production center i with type τ technology in period t
hc^t_{jP}	The unit cost of maintaining product p in the distribution center j in period t
oc^t_{mP}	Unit of operation cost on product p in collection center j in period t
rc^t_{ip}	The unit of cost of reproducing product p in the production center i in period t
nc^t_{np}	The unit cost of destroying product p at the center of destruction n in period t
fs^t_s	Fixed cost of selecting supplier s in period t
$fi^t_{i\tau}$	Fixed cost of setting up production center i with type τ technology in period t
fj^t_j	Fixed cost of setting up distribution center j in period t
fm^t_m	Fixed cost of setting up a collection center m in period t
fn^t_n	Fixed cost of setting up a destruction center n in period t
cs^t_{sr}	Supplier capacity s to supply raw material r in period t
$ci^t_{i\tau}$	Production capacity in production center i with type τ technology in period t
cj^t_j	The capacity of distribution center j in period t
cm^t_m	The capacity of collection center m in period t
cn^t_n	The capacity of destruction center n in period t
cr^t_i	Reproduction capacity in production center i in period t
$tcsi^t_{sirl1}$	The unit of cost of transporting raw material r from supplier s to production center i, with transport system $l1$ in period t
$tcij^t_{ijpl2}$	The unit cost of transferring product p from the production center i to the distribution center j with the transportation system $l2$ in period t
$tcjc^t_{jcpl3}$	The unit cost of transferring product p from the distribution center j to customer c with the transport system $l3$ in period t
$tccm^t_{cmpl4}$	Unit of cost of transferring product p from customer c to collection center m with transportation system $l4$ in period t
$tcmi^t_{mipl5}$	The unit cost of transferring product p from the collection center m to the production center i with the transport system $l5$ in period t
$tcmn^t_{mnpl6}$	The unit cost of transporting product p from the collection center m to the disposal center n with the transport system $l6$ in the period
$etsi^t_{sirl1}$	Environmental pollution resulting from the transfer of product p from the supplier s to production center i in period t with transport system $l1$
$etij^t_{ijpl2}$	Environmental pollution from product transfer p from production center i to distribution center j in period t with transportation system $l2$
$etjc^t_{jcpl3}$	Environmental pollution from product transfer p from distribution center j to customer c in period t with transportation system $l3$
$ercm^t_{cmpl4}$	Environmental pollution resulting from the transfer of product p from customer c to the collection center m in period t with the transport system $l4$
$etmi^t_{mipl5}$	Environmental pollution resulting from the transfer of product p from the collection center m to the production center i, in period t with the transport system $l5$
$etmn^t_{mnpl6}$	Environmental pollution resulting from the transfer of product p from the collection center m to the destruction center n in period t with the transport system $l6$
$em^t_{pi\tau}$	Environmental pollution caused by the production of product p in the production center i with type τ technology in period t

Table 2: Continued.

$emax^t$	Maximum acceptable level of environmental pollution in period t
tsi^t_{sirl1}	Time of transfer of one unit of raw material r from the supplier s to production center i, with transport system $l1$ in period t
tij^t_{ijpl2}	Time of transfer of a product unit p from the production center i to the distribution center j with the transport system $l2$ in period t
tjc^t_{jcpl3}	Time of transfer of a product unit p from distribution center j to customer c with transport system $l3$ in period t
tcm^t_{cmpl4}	Time of transfer of a product unit p from customer c to collection center m with transport system $l4$ in period t
tmi^t_{mipl5}	Time of transfer of a product unit p from the collection center m to the production center i, with the transport system $l5$ in period t
tmn^t_{mnpl6}	Time of transfer of a product unit p from the collection center m to the destruction center n with transport system $l6$ in period t
$fji^t_{i\tau}$	The number of days lost due to work losses during the commissioning of the production center i, with τ type technology in period t
fjj^t_j	The number of days lost due to work losses during the construction of distribution center j in period t
fjm^t_m	The number of days lost due to work losses during the construction of the collection center m in period t
fjn^t_n	The number of days lost due to work losses during the construction of the destruction center n in period t
$vji^t_{i\tau}$	Number of days lost due to work losses during production in production center i with τ type technology in period t
vjj^t_j	The number of days lost due to workers' injuries during work at the distribution center j in period t
vjm^t_m	The number of days lost due to workers' injuries during work at the collection center m in period t
vjn^t_n	Number of days lost due to workers' injuries during work at the destruction center n in period t
cr_{rp}	Raw material consumption coefficient r in product production p
$px^t_{i\tau}$	Percentage of disturbance in production capacity in production center i with τ type technology in period t
pj^t_j	Percentage of disturbance in the capacity of the distribution center j in period t
BM	A very large number
Pen	Cost of unsatisfied customer demand penalty per unit of product
γ_m	A fraction of the products used by customers that are returned to collection center m
γ_i	A fraction of the collected products that are sent to production center i
γ_n	A fraction of the collected products are sent to destruction center n
sc	Financial saving unit due to the use of reproduced products

Table 3: Parameters and levels of their values.

Level	Number of population (npop)	Maximum iteration	Percentage of crossover (Pc)	Percentage of mutation (Pm)
L1	65	65	0.55	0.2
L2	120	130	0.6	0.45
L3	190	180	0.9	0.75

constraints and exact solution methods cannot provide the optimal solution in a short and reasonable time.

On the other hand, evolutionary algorithms have performed successfully in solving various complex optimization problems. One of the unique features is their ability to solve multi-objective optimization problems as a whole. In this paper, the proposed model is optimized by non-dominated sorting genetic algorithm II (NSGAII) and the multi-objective evolutionary algorithm (MOEA).

3.1. Non-dominated Sorting Genetic Algorithm II (NSGAII). Evolutionary algorithms mimic the natural evolutionary process in nature. One of the well-considered evolutionary algorithms is the genetic algorithm (GA). This algorithm is inspired by evolutionary theory. This theory states that natural beings evolve using natural selection. Natural selection is the process of selecting and replicating the best genes from one generation to the next, which helps the new generation survive better, compete, and reproduce. Therefore, the different steps of the genetic algorithm with unsuccessful sorting to solve the model are as follows:

(1) Create an initial population with random values.

(2) Evaluate the initial population based on the value of the objective function (fitness function).

(3) Selecting parents and applying the crossover operator to create a population of children.

(4) Selecting parents and applying the mutation operator to create the mutant population.

(5) The composition of the population of parents, children, and mutants.

(6) Evaluate the new population to meet the termination requirements.

3.2. Multi-Objective Evolutionary Algorithm. The MOEA meta-heuristic algorithm is one of the most popular random search methods for solving multi-objective problems. One of the most prominent features of this algorithm is its combination of elitism, which includes two interrelated processes of maintaining reasonable solutions and returning these solutions to a growing population. In MOEA/D, the main problem with multiple goals is broken down into several sub-problems with single goals. Then all the goals are optimized at the same

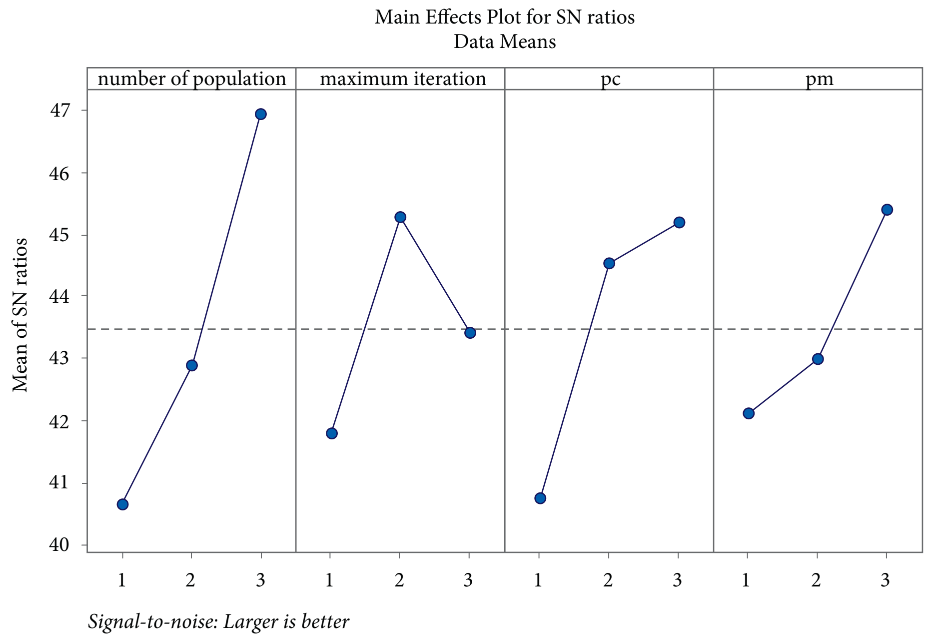

Figure 1: Mean S/N ratio at different parameter levels of NSGAII algorithm.

time. One of the competitive advantages of this method over the NSGAII algorithm is less computational complexity per generation because each sub-problem is optimized only by sub-problem information in its neighborhood. The neighborhood between these sub-problems is defined based on the Euclidean distance between their weight vectors. The MOEA can find a set of optimal solutions or Pareto solutions in one run. Therefore, the different steps of this algorithm to solve the model are as follows [7, 19].

(1) Specify the following number of problems.

(2) Calculate the distance between the generated weight vectors and select a certain number of close neighbors of each weight vector.

(3) The Pareto archive is considered to be approximately equal to empty.

(4) Generate the initial population randomly and calculate the values of the related objective functions and determine the ideal point.

(5) Generate children with the intersection operator from each of the sub-problems and their neighbors.

(6) Evaluate the new solutions obtained and, if necessary, improve the ideal.

(7) Update the Pareto archive to get non-dominated solutions.

3.3. Crossover and Mutation Operators. The intersection operator in this model is applied from a linear combination of parent-related strings according to the relation.

$$\begin{cases} y1 = ax1 + (1-\alpha)x2 \\ y2 = ax2 + (1-\alpha)x1 \end{cases}. \quad (37)$$

Moreover, for the mutation operator, a number of genes related to a chromosome are randomly selected, and then their value is randomly changed in the range [0, 1].

3.4. Parameter Tunning. Parameters of meta-heuristic algorithms have a significant effect on performance and ensure that the algorithm reaches its best solution. In this paper, the Taguchi design *f* experiment (DOE) method is applied to adjust the parameters of two meta-heuristic algorithms, NSGAII and MOEA/*D*, which according to Table 3, the parameters or influencing factors are classified into three levels:

According to the standard Taguchi design and considering four three-level factors for the NSGAII algorithm and five three-level factors for the MOEA/*D* algorithm in Minitab software, the output of the Taguchi method is illustrated in Figures 1 and 2.

4. Computational Results

In this section, the accuracy of the proposed model is examined by providing few examples. This accuracy is validated when the model can find the best possible solution. These examples are randomly generated, and the results of their solution by both algorithms are presented in Tables 4, to 6.

Since the proposed algorithm deals with the problem of optimization in several ways and their output includes several unsuccessful solutions, in order to compare the two algorithms, it is necessary to provide indicators to evaluate their outputs. In this paper, to compare the performance of the two proposed algorithms, three indices of the number of Pareto solutions (NPS), the mean to ideal distance (MID), and the diversification index (DM) have been used. As shown in Figures 3, to 5, the NSGAII algorithm in NPS and

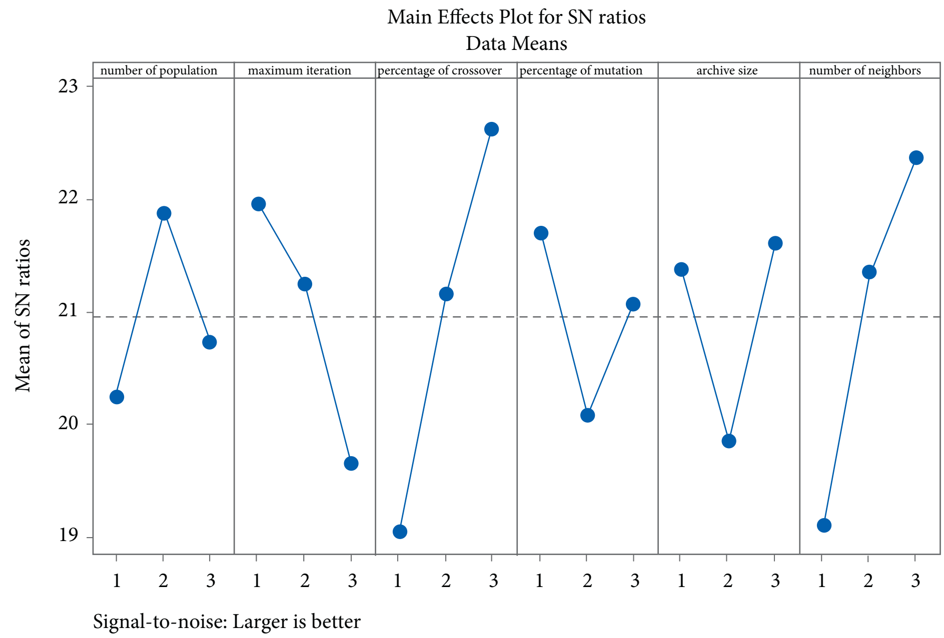

Figure 2: Mean S/N ratio at different parameter levels of MOEA/D algorithm.

Table 4: Numerical example information.

Test problem	S	$L1$	M	I	$L2$	N	J	C	P	R	T	δ	τ	$L3$	$L4$	$L5$	$L6$
1	2	2	2	2	2	1	2	6	2	2	2	2	2	2	2	2	2
2	4	2	3	2	2	2	3	8	2	3	2	2	2	2	2	2	2
3	5	2	3	3	2	2	3	10	2	3	2	2	2	2	2	2	2
4	6	2	4	4	2	2	4	12	2	3	2	3	2	2	2	2	2
5	6	3	4	4	3	3	4	14	3	3	3	2	3	3	3	3	3
6	7	3	5	5	3	4	5	16	3	3	3	3	3	3	3	3	3
7	8	3	6	5	3	5	6	18	3	4	3	3	3	3	3	3	3
8	8	3	6	5	3	5	7	20	3	4	3	3	3	3	3	3	3
9	9	4	7	6	4	6	8	24	4	4	4	4	3	4	4	4	4
10	11	4	8	7	4	7	9	28	4	4	4	4	4	4	4	4	4
11	13	4	9	8	4	8	10	32	4	4	4	4	4	4	4	4	4
12	14	5	10	9	5	9	12	40	5	5	5	4	4	5	5	5	5

Table 5: Output of MOEA/D algorithm for numerical examples.

Test problem	NPS	Mid	DM
1	7	5.32	414.28
2	6	7.61	562.67
3	20	6.52	542.02
4	12	4.87	585.9
5	11	9.01	2085.6
6	11	5.41	1478.6
7	13	9.81	1772.8
8	10	7.07	1816.8
9	13	14.44	3754.6
10	17	13.47	4081.6
11	20	23.12	4867.6
12	21	28.10	6668.3

Table 6: Output of NSGAII algorithm for numerical examples.

Test problem	NPS	Mid	DM
1	45	12.64	795.03
2	22	11.93	1415.5
3	32	15.49	1668.8
4	44	12.52	1431.8
5	22	18.8	2893.1
6	16	23.53	3761.1
7	18	20.86	3157
8	7	16.08	3074.9
9	23	29.63	6796.6
10	15	34.61	7146.8
11	26	37.41	7615.9
12	13	40.18	9926.2

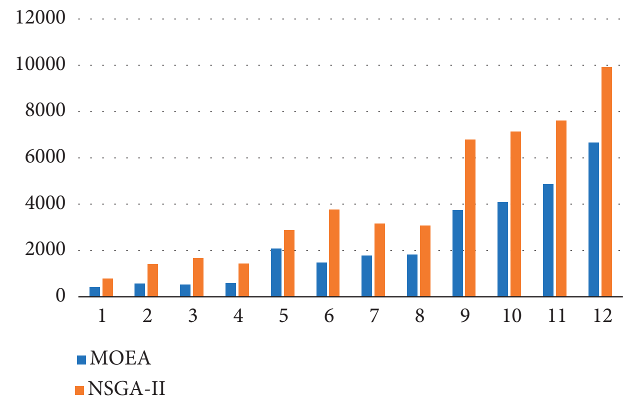

Figure 3: Comparison of algorithms based on DM index.

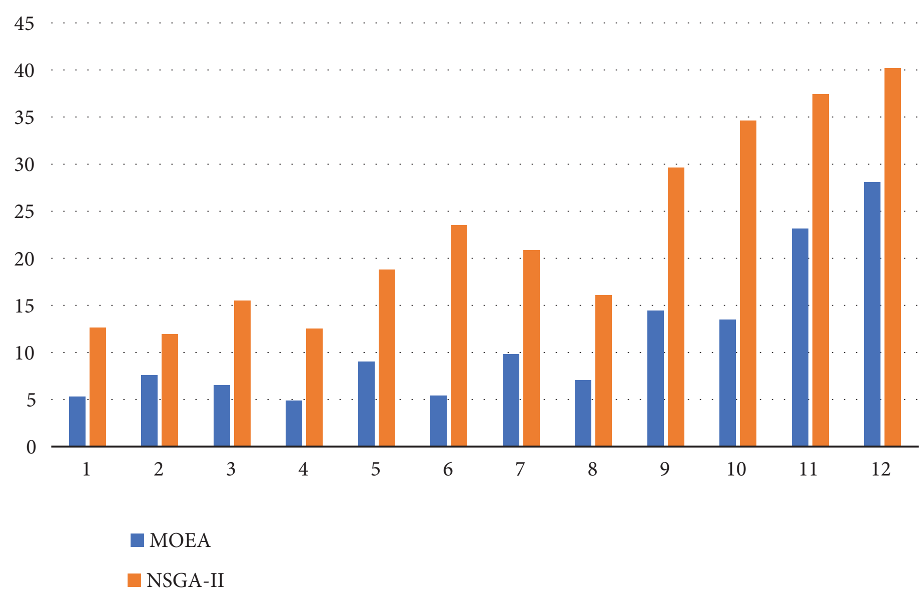

Figure 4: Comparison of algorithms based on MID index.

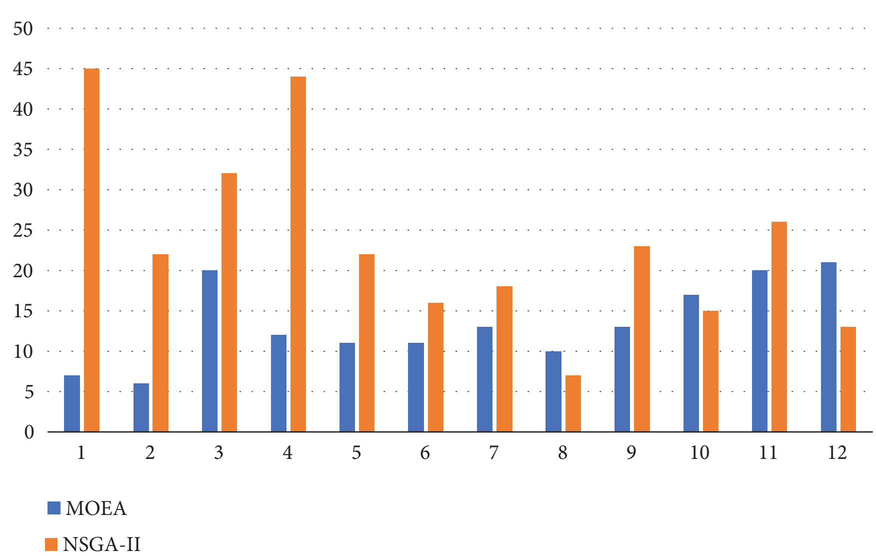

Figure 5: Comparison of algorithms based on NPS index.

DM is relatively superior to the MOEA/*D* algorithm, while in the MID index, the MOEA/*D* algorithm is superior.

5. Conclusion

In today's world, supply chain sustainability builds a company's competitiveness and improves its performance. To this end, a supply chain ensures its sustainable success by considering various sustainability dimensions, including economic, social, and environmental areas. On the other hand, hiring and retaining forces that have unique capabilities and motivation is the most effective factor of productivity in the organization.

Moreover, increasing attention to environmental issues has doubled the importance of designing closed-loop supply chains that include waste generation, recycling, and disposal. The integrated design of closed-loop supply chain networks is one of the critical issues in supply chain management, including determining the location and number of required facilities (production, collection, recycling, and destruction) in the forward and reverse supply chain.

In this paper, an optimization model for multi-level, multi-period, and multi-product closed-loop SCND with consideration of sustainability and resilience was presented. All three social aspects, environmental and economic, were considered in the supply chain sustainability dimension, and in the resilience dimension, disturbances in production and distribution capacity were considered. The relevant model has three objective functions, the first objective function is related to profit maximization, the second objective function is related to minimizing delivery time, and the third objective function is related to increasing social responsibility. In the third objective, the function is done by reducing lost working days. Moreover, due to the NP-hard nature of the model, two meta-heuristic algorithms NSGAII and MOEA/*D*, were used to solve it. Finally, according to the evaluation indicators provided, the efficiency of both algorithms in solving the optimization model can be observed.

In this research, a comprehensive approach was presented to distributing perishable products. This approach, based on the design of the supply chain network, tries to provide the best possible solution for the distribution of perishable products and their waste management. From a managerial point of view, using this research can increase the shelf life of perishable products and reduce their waste. Moreover, the implemented solution methods in this research, by providing several solutions, allow the decision makers to choose the best one by comparing the solutions.

In order to develop this research, it is suggested to consider the demand as an uncertain parameter and to use possible and stable approaches to deal with it. Furthermore, other multi-objective meta-heuristic algorithms such as multi-objective gray wolf optimizer and multi-objective red deer algorithm are suggested [20].

Data Availability

The data are available in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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