Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9370440, 10 pages
https://doi.org/10.1155/2022/9370440

Research Article

A Developed Mathematical Model for Designing a Multilevel Sustainable Supply Chain Network Taking into Account Environmental Decisions

Mehrab Paydarfard[1] **Roya Pirzadeh**[2] **Ali Ahmadi**[3] **Masoud Zohrabi**[4] **Farkhondeh Mortaz Hejri**[5] **and Malek Hasan**[6]

[1]*Department of Business Management, Faculty of Management, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[2]*Master of IT Engineering, Faculty of Electrical, Mechanical and Computer, University Of Eyvanakey, Eyvanki, Iran*
[3]*Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*
[4]*Information Technology Management, Faculty of Management and Accounting, Allameh Tabatabai University, Tehran, Iran*
[5]*Department of IT Management, Faculty of Management, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[6]*Department of Medical Instruments Engineering Techniques, Al-Farahidi University, Baghdad 10021, Iraq*

Correspondence should be addressed to Mehrab Paydarfard; st_m_paydarfard@azad.ac.ir

Received 29 May 2022; Revised 8 July 2022; Accepted 31 August 2022; Published 19 September 2022

Academic Editor: Abdellatif Ben Makhlouf

In this research, a novel mathematical model for sustainable supply chain network design is proposed. The main contribution and novelty of this research are considering environmentally friendly facilities and several thresholds for emitted pollution, which bring this research closer to real-world conditions. Since the amount of pollution produced by different supply chain facilities is not the same, it is better to make different decisions regarding each repair and renovation measure, i.e., environmental decisions should be considered step-by-step. In addition, the proposed model was optimized by the whale optimization algorithm (WOA) to find the best solution in large-scale instances in a short and reasonable time. Finally, the performance of the proposed model and the reduction of environmental impacts to improve the stability of logistics systems are reviewed in a case study. The results of the computational analysis show the efficiency of the proposed model.

1. Introduction

The growing global environmental awareness and the increase of laws and regulations have made the approach to sustainability. Most companies are moving to sustainable supply chain management, addressing environmental issues throughout the supply chain. As Govindan et al. [1] state, about half of the logistics articles have been designed for the green supply chain network, and those interested have been suggested to study this important issue. Eco-friendly facilities can operate in the supply chain network, and others need to be repaired [1].

If their environmental impacts exceed the initial allowable, repairs should be made to reduce pollution to some extent. However, general repairs and possibly renovation should be done if the amount of pollution is more than the allowable secondary level [2]. In this regard, measuring the level of emissions is significantly essential. It can help the supply chains for finding the core of environmental issues and resolve them.

In this regard, some specific measures can be assessed. Measures such as overhaul, improvement of production methods, and modernization of machinery can be applied in different supply chains. This strategy will ensure that the supply chain does minor damage to the environment. If this issue is ignored, the environmental effects will increase and lead to many social problems, such as citizens' diseases. To the best of the authors' knowledge, the research items in the supply chain network design field have not focused on this important issue. Accordingly, in order to cope with the effect of environmental and social objectives of the supply chains, in this study, attention to environmental effects is presented from two aspects to reduce these effects significantly [3].

In this research, in the first aspect, each producer's amount of pollution is calculated and measured with two thresholds every few years [4]. This measure is considered to calculate the erode of equipment and facilities over time. Moreover, the second aspect of reducing environmental impact is choosing the type of transportation system. Another aspect of this research is dealing with selecting the transportation system to reach sustainability. In this regard, a multiobjective mathematical model for designing a closed-loop supply chain with environmental and social aspects is proposed. In this model, the best transportation system is selected based on the economic and environmental aspects of the supply chain.

After careful consideration of the previous related works, the main contribution of this research can be summarized as follows:

(i) Proposing a multiobjective mathematical model for designing a closed-loop supply chain with environmental and social aspects

(ii) Considering several thresholds for emitted pollution and considering environmental decisions

(iii) Optimizing the proposed mathematical model with the WOA algorithm

The remainder of this paper is organized as follows: in Section 2, the literature is reviewed. In Section 3, the formulated model is presented. Section 4 provides the proposed solution method. Section 5 presents our experimental results, and Section 6 offers our conclusion and future research directions.

2. Literature Review

Research on the design of the supply chain network and environmental protection can be divided into the following categories: minimizing the effects of greenhouse gases ([5, 6]), implementing carbon policies ([7] and [8]), waste reduction ([9]), attention to water ([10]), and other environmental aspects such as fuel and energy consumption ([11]).

As previously mentioned, in this research, by considering the proposed model, it is possible to select a transportation system based on both economic and environmental objectives, which is one of the advantages of this research.

It should also be noted that the focus on supply chain coordination is rapidly expanding in the global market [12]. Accordingly, coordination [13] measures should focus on transportation decisions, pricing, and inventory [14]. As can be seen in the literature, more effective results can be achieved by considering these tactical decisions together ([15, 16]).

Recently, researchers have focused on novel assumptions for supply chain network design. Tavana et al. [17] proposed a sustainable supply chain network design by considering the cross-docking in the distribution throughout the supply chain. Moreover, location-inventory-routing, time window, supplier selection, order allocation, transportation modes with simultaneous pickup, and delivery under uncertainty were of concern in this research. Delfani et al. [18] proposed a robust fuzzy mathematical model for a pharmaceutical supply chain network design problem. They considered reliability and delivery time. They solved this problem using the red deer algorithm (RDA). Foroozesh et al. [19] optimized a closed-loop supply chain for perishable products by considering route risk and horizontal collaboration. They applied a robust possibilistic programming approach with credibility measures to deal with demand and cost uncertainty.

Shekarian et al. [20] provided a comprehensive systematic review of sustainable supply chain management with industrial practices. They have proposed novel interpretation of the sustainable solutions addressed by different industries and present a new and updated classification of the literature identifying future directions. Yu et al. [21] assessed supply chain management with sustainable and green technologies. In this research, reducing waste from different levels of the supply chain using novel technologies is emphasized. Soni et al. [22] proposed a decision-making framework for the implementation of Industry 4.0 in sustainable supply chains. This research indicates that small and median-sized enterprises can enhance their working capital and competitiveness by adopting Industry 4.0 technologies for sustainable supply chain finance.

According to the content of recent research articles and researchers' suggestions and real-world needs, in the study, the design of a sustainable supply chain network takes into account economic and environmental issues along with integrating important and effective tactical decisions which is of concern. Moreover, the present study seeks to reduce the destructive effects on the environment by choosing the best transportation system. In addition, price is one of the decision variables, and customer demand can be assumed as a function of this variable. Accordingly, in this research, for the first time, several thresholds for the amount of emitted pollution are considered in order to prevent the excessive increase of pollution and to help protect the environment, based on which decisions are made regarding the renovation and repair of polluting facilities. Moreover, this model is optimized with WOA, and the performance of this algorithm is investigated.

3. Research Methodology

In this section, the proposed mathematical model is presented. First, the assumptions of the model are expressed. Next, sets, parameters, and variables are introduced. Finally, the equations of the model are provided. The structure of the research methodology is as shown in Figure 1.

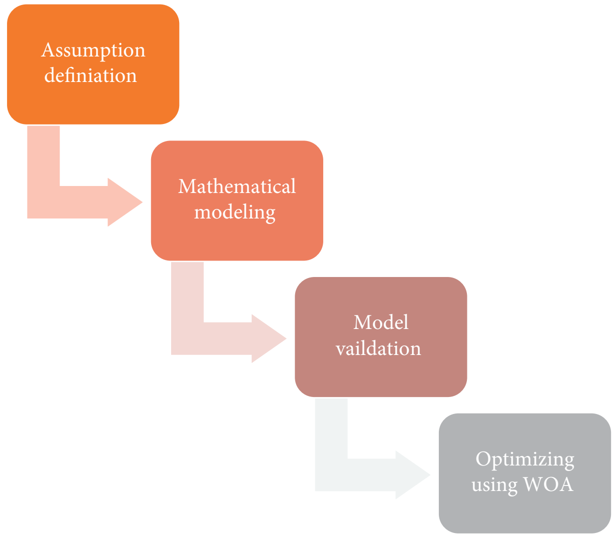

Figure 1: The research framework.

In this research, a multiperiod and multiproduct supply chain network design model is proposed, including two levels of manufacturers and customers. In each tactical period, product prices are determined, and inventory decisions are made. To send products to customers, several types of transportation systems are selected as the least expensive and most environmentally friendly. The level of pollution of each producer is evaluated at the end of each strategic period, and based on it, one of the following three decisions is selected:

If the pollution level is less than the initial allowable threshold ($\theta 1$), no action is taken.

If the amount of pollution is more than $\theta 1$ and less than the allowable secondary threshold ($\theta 2$), the amount of pollution will be reduced with minor repairs.

If the amount of pollution is more than that$\theta 2$, general repairs should be done, and the amount of pollution should reach zero.

3.1. Assumptions

(1) This model considers two horizons of strategic and tactical time planning. Each strategic period includes several tactical periods ([20, 21]).

(2) At the beginning of the program horizon, the inventory is zero, and it is assumed that the inventory of the last tactical period in each strategic period is transferred to the first tactical period of the following strategic period.

(3) Pollution generated in each period is considered cumulatively with previous periods. If minor repairs are made, a percentage of the previous period's emissions that have not been lost will be collected, and if major repairs are made, it is assumed that all contaminants from previous periods have been removed.

Definitions of sets, parameters, and decision variables are provided in the following subsections.

3.2. Sets. Set of candidate points for manufacturers $i \epsilon I$, I.

Customer points collection $j \epsilon J$, J.

Product Collection $p \epsilon P$, P.

A set of tactical time periods $t \epsilon T$, T.

A set of strategic time periods $s \epsilon S$, S.

Set of price levels $l \epsilon L$, L.

Collection of transportation systems $r \epsilon R$, R.

3.3. Parameters. b_{plst} Price for product p with price level l in tactical period t and strategic period s.

d_{jplst} Customer j demand for product p with price level l in tactical period t and strategic period s.

c_{ijpr} Cost of sending a unit of product p from the manufacturer i to the customer j by shipping type r.

n_{ip} Production cost per unit of product p per manufacturer i.

f_i Manufacturer i construction cost.

m_{ip} Maximum production capacity to produce product p in manufacturer i per period.

h_{ip} Cost of keeping product p in the manufacturer i warehouse.

g Minor repair cost in the supply chain.

k Overhaul costs.

e_{ip} Pollution rate per product p in producer i.

v_{ijpr} Pollution rate per unit of product p sent from manufacturer i to customer j by transport type r.

$\theta 1$ Threshold for minor repairs.

$\theta 2$ Threshold for general repairs.

λ Percentage of pollution that is eliminated by minor repairs.

BN A very large number.

3.4. Decision Variables. q_{is} The amount of pollution produced by the manufacturer i in the strategic period s.

w_{ijpst} Manufacturer i share to meet customer j demand for the product p in the tactical period t and the strategic period s.

Z_{ijprst} The amount of product p sent from the manufacturer i to the customer j by transport type r in the tactical period t and the strategic period s.

u_{ipst} The amount of product p kept in the manufacturer i in the tactical period t and the strategic period s.

x_i 1 If the manufacturer i is constructed and 0, otherwise.

y_{plst} 1 If the price level l for product p is selected in the tactical period t and the strategic period s and 0, otherwise.

$a1_{\text{is}}$ 1 If the level of pollution in the manufacturer i is less than the initial allowable threshold and no action is taken in the strategic period s.

$a2_{\text{is}}$ 1 If the amount of pollution is more than the initial allowable threshold and less than the secondary allowable threshold and minor repairs are made in the manufacturer i and strategic period s.

$a3_{\text{is}}$ 1 If the amount of pollution is more than the allowable secondary threshold and is done in the manufacturer i and strategic period s.

3.5. Mathematical Formulation

$$\begin{aligned}\max Z1 = &\sum_j\sum_p\sum_l\sum_s\sum_t b_{\text{plst}} d_{\text{jplst}} y_{\text{plst}} \\ &- \sum_i f_i x_i \\ &- \sum_i\sum_j\sum_p\sum_s\sum_t n_{\text{ip}} w_{\text{ijpst}} \\ &- \sum_i\sum_j\sum_p\sum_r\sum_s\sum_t c_{\text{ijpr}} z_{\text{ijprst}} \\ &- \sum_i\sum_p\sum_s\sum_t h_{\text{ip}} u_{\text{ipst}} \\ &- g\sum_i\sum_s a2_{\text{is}} - k\sum_i\sum_s a3_{\text{is}}.\end{aligned} \tag{1}$$

$$\min Z2 = \sum_i\sum_j\sum_p\sum_r\sum_s\sum_t v_{\text{ijpr}} z_{\text{ijprst}}, \tag{2}$$

s.t,

$$\sum_i w_{\text{ijpst}} = \sum_l \left(d_{\text{jplst}} y_{\text{plst}}\right) \quad \forall j,\ p,\ s,\ t, \tag{3}$$

$$\sum_l y_{\text{plst}} = 1 \quad \forall p,\ s,\ t, \tag{4}$$

$$\sum_j w_{\text{ijpst}} \le m_{\text{ip}} x_i \quad \forall i,\ p,\ s,\ t, \tag{5}$$

$$u_{i,p,s,t-1} + \sum_j w_{\text{ijpst}} = u_{\text{ipst}} + \sum_j\sum_r z_{\text{ijrpst}}\ \forall i,\ p,\ s,\ t \ge 2, \tag{6}$$

$$u_{i,p,s-1,T} + \sum_j W_{i,j,p,s,1} = u_{i,p,s,1} + \sum_v\sum_r z_{i,j,r,p,s,1}\ \forall i,\ p,\ s \ge 2, \tag{7}$$

$$q_{i,1} = \sum_j\sum_p\sum_t e_{\text{ip}} w_{\text{ijp1t}} \quad \forall i,\ s = 1, \tag{8}$$

$$\begin{aligned}q_{is} = &\sum_j\sum_p\sum_t e_{\text{ip}} w_{\text{ijpst}} + q_{i,s-1} a1_{i,s-1} \\ &+ (1-\lambda) q_{i,s-1} \times a2_{i,s-1} \quad \forall i,\ s \ge 2,\end{aligned} \tag{9}$$

$$q_{\text{is}} \le \theta 1 a1_{\text{is}} + \theta 2 a2_{\text{is}} + BNa3_{\text{is}} \quad \forall i,\ s, \tag{10}$$

$$q1_{\text{is}} + a2_{\text{is}} + a3_{\text{is}} = 1 \quad \forall i,\ s, \tag{11}$$

$$q_{\text{is}} \ge 0 \quad \forall i,\ s, \tag{12}$$

$$w_{\text{ijpst}}, z_{\text{ijprst}}, u_{\text{ijpst}} \ge 0 \text{ and Integer} \quad \forall i,\ j,\ p,\ r,\ s,\ t, \tag{13}$$

$$x_i, y_{\text{plst}}, al_{\text{is}}, a2_{\text{is}}, a3_{\text{is}} \epsilon \{0,1\} \quad \forall i,\ p,\ l,\ s,\ t. \tag{14}$$

The objective function (1) seeks to maximize income and minimize the costs of the supply chain. In other words, Z1 demonstrates the net profit of the supply chain. The first term is the total income of the supply chain. The rest terms are the cost of construction, production, transportation, product maintenance, minor repairs, and overhauls, respectively.

Based on the objective function (2), the transportation system is selected that causes less damage to the environment. Constraint (3) is to balance the number of goods produced and customer demand. Based on Constraint (4), only one price level is selected for each product in each period. Capacity Constraint (5) limits the amount of production of each factory. Constraints (6) and (7) indicate the inventory balance constraints in the factory and equalize the amount of inventory of the previous period plus the goods produced in this period with the amount of inventory and goods sent in the same period. Constraint (8) shows the amount of pollution in the first strategic period, and Constraint (9) shows the amount of pollution in other strategic periods. Based on Constraints (10) and (11) corresponding to the pollution created and the pollution thresholds, the optimal decision is made. The type of decision variables is determined by Constraints (12) to (14).

It should be noted that the proposed model contains several nonlinear expressions. After linearizing the model, it is used to integrate the two objective functions of the proposed method of Allaoui et al. [10] and then is optimized using GAMS optimization software and the whale optimization algorithm.

4. Whale Optimization Algorithm (WOA)

Whales, like many animals, have a collective lifestyle. Whales hunt deep-sea fish for food. In this regard, studies such as [23] have [24] modeled [25] an approximate [26] optimization method by modeling the group lifestyle of whales. The WOA algorithm is performed in three steps such as hunting, exploitation, and exploration.

4.1. Hunting in WOA. Whales can identify hunting grounds and surround them. Once the best search engine is identified, other search agents try to update their location relative to the best search engine. This behavior is expressed through equation (15) and equation (16) which are mentioned as follows:

$$\overrightarrow{D} = \left|C.X^{*}(t) - X(t)\right|, \tag{15}$$

$$X(t+1) = X^{*}(t) - \overrightarrow{A}.\overrightarrow{D}, \tag{16}$$

where t denotes the current iteration, A and C are the coefficient vectors, X^{*} is the best solution obtained at present, and X is the location vector. A and C are calculated as (17) and (18) shown as follows:

$$\overrightarrow{A} = 2\overrightarrow{a}.\overrightarrow{r} - \overrightarrow{a}, \tag{17}$$

$$\overrightarrow{C} = 2.\overrightarrow{r}. \tag{18}$$

4.2. Exploitation and Exploration. Two methods have been designed for the mathematical modeling of exploration and exploitation.

(a) Mechanism of contractile blockade: this behavior is achieved by increasing the value of a in (17).

(b) Spiral updating location: this method first calculates the distance between the whale located in the X and Y coordinates of the bait in X^{*} and Y^{*} in which (19) is used.

$$x(t+1) = \overrightarrow{W'}.e^{\varphi l}.\ \cos(2\pi l) + X^{*}(t), \tag{19}$$

where W 'refers to the distance from the first whale to the prey, and φ is a constant for defining the shape of a logarithmic helix and is a random number between 1 and -1. It should be noted that the humpback whale swims around its prey along a contractile circle and at the same time in a spiral path. This is calculated according to equation (20)shownas follows:

$$x(t+1) = \left\{ \begin{array}{ll} X^{*}(t) - \overrightarrow{A}.\overrightarrow{D} & \text{if rand} < 0.5 \\ \overrightarrow{D'}.e^{\varphi l}.\ \cos(2\pi l) + X^{*}(t) & \text{if and} \geq 0.5 \end{array} \right\}, \tag{20}$$

where and is a random number between 0 and 1. In addition to the net bubble method, humpback whales randomly search for preys. Finally, the WOA algorithm ends by satisfying the termination conditions. Figure 2 shows the pseudocode of the WOA algorithm.

```
Initialize the whales population Xi (i = 1, 2, ..., n)
Calculate the fitness of each search agent
X*=the best search agent
while (t < maximum number of iterations)
    for each search agent
    Update a, A, C, l, and p
        if 1 (p<0.5)
            if 2 (|A|<1)
                Update the position of the current search agent by the Eq. (2.1)
            else if 2 (|A|≥1)
                Select a random search agent (Xrand)
                Update the position of the current search agent by the Eq. (2.8)
            end if 2
        else if 1 (p≥0.5)
                Update the position of the current search agent by the Eq. (2.5)
        end if 1
    end for
    Check if any search agent goes beyond the search space and amend it
    Calculate the fitness of each search agent
    Update X* if there is a better solution
    t=t+1
end while
return X*
```

Figure 2: The structure of the whale optimization algorithm [20].

5. Numerical Results

In the proposed paper, for the first time, multilevel repairs are added to the problem of supply chain network design, which can significantly help to protect the environment. As mentioned earlier, since transportation is considered the most polluting activity in the supply chain network and has received less attention in the articles; one of the advantages of the proposed model is the reduction of pollution caused by transportation. The transportation system is chosen to cause the least damage to the environment. In this section, we seek to substantiate these claims for a case study of the electrical supply chain adapted from Shuang et al. [24].

The proposed model is more efficient from an environmental point of view than other previous models. Without considering the second objective function, the least costly type of transportation is selected, but if the amount of environmental impacts caused by transportation is minimized, 16% $(100 \times 165793 - 142907.142907)$ of environmental impacts can be achieved. Moreover, because the facilities are inspected and repaired every few years, they have less environmental impact, which causes 170% $(5568 - 20599.20599)$ less damage to the environment than other models that ignore repair decisions.

In order to show the accuracy of the proposed model, several sensitivity analyzes are performed concerning the main advantage of the paper, namely environmental decisions with step levels.

The first sensitivity analysis is related to the performance of two factories in 3 strategic periods with a threshold of 8000 and 15000, respectively. As shown in Figure 3, the pollution of the first plant in strategic periods 1 and 3 exceeded the initial threshold, and with minor repairs, some of its environmental effects have been reduced. In period 2, due to increased pollution and exceeding the second threshold and general repairs, a significant reduction in environmental impact is observed. The second factory had a lower level of pollution than the secondary limit, and no general repairs were made.

By increasing the permissible limits, factories create more pollution. To show this discussion and validate the performance of the sensitivity analysis model to the threshold of minor repairs (in which the amount of pollution produced is more sensitive to this parameter), and the result is shown in Figure 4.

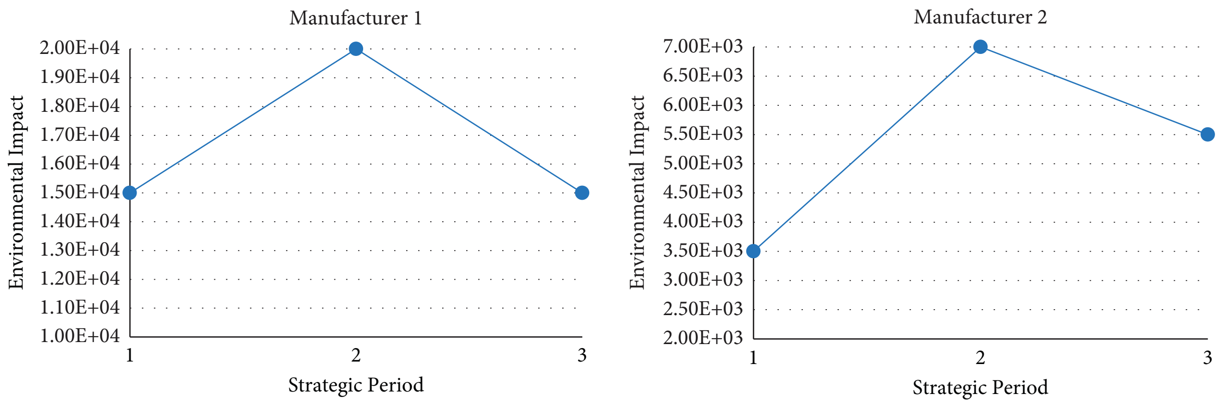

Figure 3: Total pollution produced by the first and second factories in strategic periods.

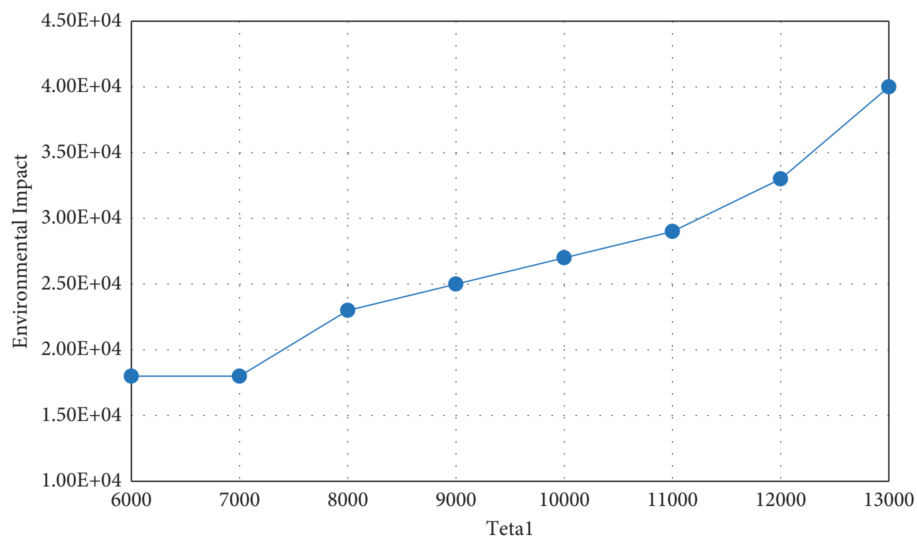

Figure 4: Effect of the initial allowable threshold on pollution.

Table 1: Parameters and their levels for the WOA.

Parameters	Levels		
	Level 1	Level 2	Level 3
Stopping criteria	70	90	130
Number of whales	70	80	90
Position controlling parameter	0.1	0.2	0.3

5.1. Evaluating the Performance of the WOA. In order to design experiments in the WOA algorithm, three different levels are first defined for their parameters. Then, predefined experiments are performed in this algorithm. The proposed values for the parameters of this algorithm are shown in Table 1. The parameters are stopping criteria, the number of whales, and the change rate.

Next, with the Taguchi L9 design, different experiments were created, and the WOA algorithm was implemented for each of them. The implementation results are presented in Table 2.

Next, by presenting these outputs to MINITAB software, the S/N ratio is obtained and presented in Figure 5.

Finally, based on the output presented in Figure 4, the optimal value of the stopping criteria, number of whales, and position controlling parameter is equal to 130, 80, and 0.1, respectively. To compare the methods based on the studied indicators, 10 test problems in different dimensions were generated. It should be noted that for each of the methods of solving, the time limit of 3600 seconds is considered, and the limits of the problems produced are presented in Table 3.

These test problems are implemented using the WOA method in MATLAB software as well as the Epsilon restriction method (EPC) in GAMS software. The two methods of solving the value of quality indicators are the solution to the problem and are reported in Tables 4 and 5.

In order to compare the methods based on the MID index, the average for the Epsilon constraint was 18.60 and for the WOA algorithm was 23.25. In a similar way, for the max-spread index, the average for the Epsilon constraint was 22.26 and for the WOA algorithm was 29.65. Figures 6 and 7 show the trend of MID and max-spread, respectively.

The mid and max-spread index results show that the WOA algorithm has better values than EPC in all cases.

Table 2: Details of implementing the Taguchi method for the WOA.

Implement number	Parameters			Output index
	Max_iter	N_S	PR	
1	1	1	1	0.679
2	1	2	2	0.712
3	1	3	3	0.682
4	2	1	2	0.663
5	2	2	3	0.702
6	2	3	1	0.681
7	3	1	3	0.647
8	3	2	1	0.739
9	3	3	2	0.739

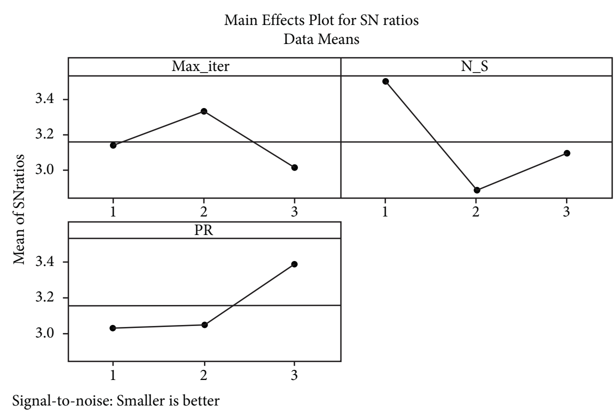

Figure 5: Taguchi results for the WOA parameters.

Table 3: Information on numerical test problems.

Test problem	Number of manufacturers	Number of customers	Number of products	Number of price levels	Number of transportation systems	Number of tactical periods	Number of strategic periods
1	5	8	1	1	1	7	1
2	7	10	2	2	1	7	2
3	9	12	3	3	1	9	3
4	11	15	4	4	2	9	4
5	13	20	5	5	2	12	5
6	15	25	7	6	2	12	7
7	17	30	9	7	3	15	9
8	19	35	11	8	3	15	11
9	21	40	30	9	3	20	13
10	23	45	15	10	4	20	15

Table 4: Epsilon constraint output for solved examples.

Test problem	MID	Max-spread	CPU time
1	14.434	10.821	6.65
2	15.393	11.330	13.28
3	16.023	13.924	84.47
4	16.828	14.454	458.80
5	18.037	15.564	1065.23
6	20.162	22.265	1381.91
7	21.523	28.920	2707.90
8	22.113	40.798	3600.00
9	22.915	42.313	3600.00
10	0.000	0.000	Not solved
Average	18.603	22.265	1435.360

Table 5: WOA output for solved examples.

Test problem	MID	Max-spread	CPU time
1	20.029	9.146	14.93184
2	19.086	17.428	16.58137
3	17.291	15.282	35.45572
4	18.770	20.291	59.27535
5	25.826	20.021	79.87993
6	19.700	28.746	103.0917
7	29.528	35.436	134.1118
8	31.792	48.660	135.7111
9	25.729	46.795	170.0785
10	24.839	54.691	171.0802
Average	23.259	29.650	92.01974

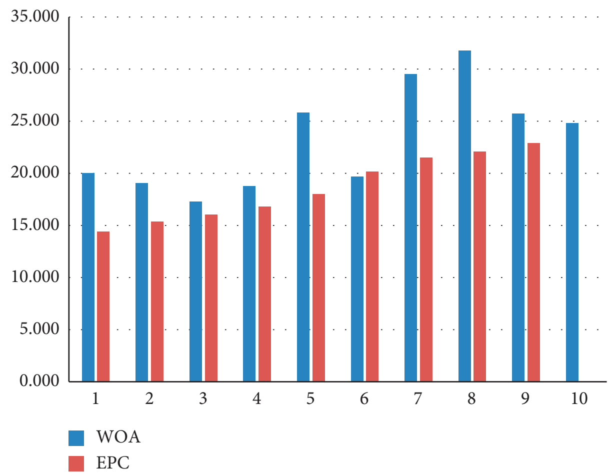

FIGURE 6: Comparison of solution methods based on a MID index.

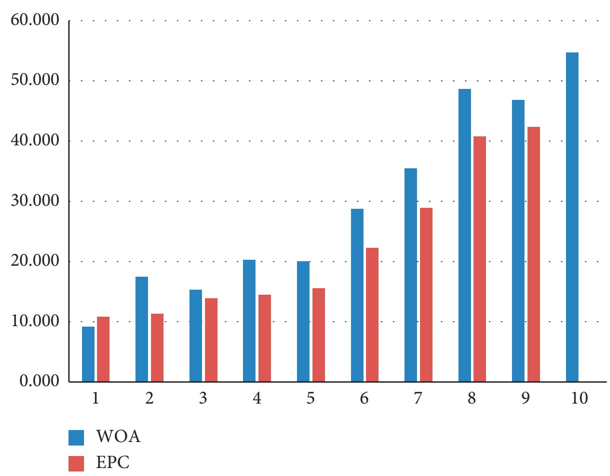

FIGURE 7: Comparison of solution methods based on the max-spread index.

Moreover, according to Figures 6 and 7, when comparing the method based on the max-spread index, the EPC method was only able to provide a better solution in comparison to WOA in the first test problem.

6. Conclusion

In the present study, a new model for designing a multi-product-multiperiod supply chain network is proposed and analyzed. Considering criteria such as paying attention to the environment, choosing the type of transportation system, addressing tactical decisions, and so on make the models more efficient and closer to the real world, so in this research, they have been addressed. To improve the network from an environmental point of view, the choice of the type of transportation system is considered, and it is shown that this policy can reduce costs and further protect the environment. Moreover, in this research, for the first time, several thresholds for the amount of emitted pollution are considered to prevent the excessive increase of pollution and help to protect the environment, based on which decisions are made to renovate and repair polluting facilities. It is clear that the benefits of reducing environmental impacts, in addition to supply chain stakeholders, will also have beneficial effects on society. Solving a real case study and performing various sensitivity analyses show that the proposed supply chain network design model is less costly, leads to keeping the environment clean, and can promote sustainable development.

Moreover, the WOA algorithm was used to solve the proposed large-scale mathematical model in this research. The results of using this meta-heuristic algorithm show that this method can obtain Pareto solutions with very little time compared to the EPC method. Moreover, the quality of this algorithm in terms of MID and max-spread indices is much better than EPC.

In this research, in order to provide management insights, an approximate approach was used to solve the mathematical model. It should be noted that classical solution methods cannot be suitable for closed-loop supply chain network design due to their complexity and high CPU time. For this reason, by implementing the WOA algorithm, a set of optimal solutions can be presented to supply chain managers, which can help make the decisions easier.

Finally, for future research, it is suggested that a variety of inventory control systems, as well as pricing policies, be added to the supply chain network design problem. Moreover, by considering the reverse logistics and closed-loop supply chain, it is possible to help protect the environment as much as possible. [27–34].

Data Availability

Data are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] K. Govindan, H. Soleimani, and D. Kannan, "Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future," *European Journal of Operational Research*, vol. 240, no. 3, pp. 603–626, 2015.

[2] A. Pourghader chobar, M. Sabk Ara, S. Moradi Pirbalouti, M. Khadem, and S. Bahrami, "A multi-objective location-routing problem model for multi-device relief logistics under uncertainty using meta-heuristic algorithm," *Journal of Applied Research on Industrial Engineering*, vol. 85, pp. 5–8, 2021.

[3] P. Ghasemi, H. A. Khalili, A. P. Chobar, S. Safavi, and F. M. Hejri, "A New Multiechelon Mathematical Modeling for Pre-and Postdisaster Blood Supply Chain: Robust Optimization Approach," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2976929, 10 pages, 2022.

[4] M. Sherafati and M. Bashiri, "Closed loop supply chain network design with fuzzy tactical decisions," *Journal of Industrial Engineering International*, vol. 12, no. 3, pp. 255–269, 2016.

[5] Y. C. Tsao, V. V. Thanh, J. C. Lu, and V. Yu, "Designing sustainable supply chain networks under uncertain

environments: fuzzy multi-objective programming," *Journal of Cleaner Production*, vol. 174, pp. 1550–1565, 2018.

[6] M. Ouhimmou, M. Rönnqvist, and L.-A. Lapointe, "Assessment of sustainable integration of new products into value chain through a generic decision support model: an application to the forest value chain," *Omega*, vol. 99, Article ID 102173, 2021.

[7] M. Sherafati, M. Bashiri, R. T. Moghaddam, and M. S. Pishvaee, "Achieving sustainable development of supply chain by incorporating various carbon regulatory mechanisms," *Transportation Research Part D: Transport and Environment*, vol. 81, Article ID 102253, 2020.

[8] V. Lahri, K. Shaw, and A. Ishizaka, "Sustainable supply chain network design problem: using the integrated BWM, TOPSIS, possibilistic programming, and ε-constrained methods," *Expert Systems with Applications*, vol. 168, Article ID 114373, 2021.

[9] C. Arampantzi and I. Minis, "A new model for designing sustainable supply chain networks and its application to a global manufacturer," *Journal of Cleaner Production*, vol. 156, pp. 276–292, 2017.

[10] H. Allaoui, Y. Guo, A. Choudhary, and J. Bloemhof, "Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach," *Computers & Operations Research*, vol. 89, pp. 369–384, 2018.

[11] F. Maadanpour Safari, F. Etebari, and A. Pourghader Chobar, "Modelling and optimization of a tri-objective Transportation-Location-Routing Problem considering route reliability: using MOGWO, MOPSO, MOWCA and NSGA-II," *Journal of optimization in industrial engineering*, vol. 14, no. 2, pp. 83–98, 2021.

[12] S. Çetinkaya and C.-Y. Lee, "Stock replenishment and shipment scheduling for vendor-managed inventory systems," *Management Science*, vol. 46, no. 2, pp. 217–232, 2000.

[13] A. Goli, E. B. Tirkolaee, and G. W. Weber, "A perishable product sustainable supply chain network design problem with lead time and customer satisfaction using a hybrid whale-genetic algorithm," in *Logistics Operations and Management for Recycling and Reuse*, pp. 99–124, Springer, Berlin, Heidelberg, 2020.

[14] K. S. Hong and C. Lee, "Optimal time-based consolidation policy with price sensitive demand," *International Journal of Production Economics*, vol. 143, no. 2, pp. 275–284, 2013.

[15] M. Rahmaty, A. Daneshvar, F. Salahi, M. Ebrahimi, and A. P. Chobar, "Customer churn modeling via the grey wolf optimizer and ensemble neural networks," *Discrete Dynamics in Nature and Society*, vol. 202212 pages, Article ID 9390768, 2022.

[16] F. Y. Chen, T. Wang, and T. Z. Xu, "Integrated inventory replenishment and temporal shipment consolidation: a comparison of quantity-based and time-based models," *Annals of Operations Research*, vol. 135, no. 1, pp. 197–210, 2005.

[17] M. Tavana, H. Kian, A. K. Nasr, K. Govindan, and H. Mina, "A comprehensive framework for sustainable closed-loop supply chain network design," *Journal of Cleaner Production*, vol. 332, Article ID 129777, 2022.

[18] F. Delfani, H. Samanipour, H. Beiki, A. V. Yumashev, and E. M. Akhmetshin, "A robust fuzzy optimisation for a multi-objective pharmaceutical supply chain network design problem considering reliability and delivery time," *International Journal of Systems Science: Operations & Logistics*, vol. 9, no. 2, pp. 155–179, 2022.

[19] N. Foroozesh, B. Karimi, and S. M. Mousavi, "Green-resilient supply chain network design for perishable products considering route risk and horizontal collaboration under robust interval-valued type-2 fuzzy uncertainty: a case study in food industry," *Journal of Environmental Management*, vol. 307, Article ID 114470, 2022.

[20] A. Pourghader Chobar, M. A. Adibi, and A. Kazemi, "A novel multi-objective model for hub location problem considering dynamic demand and environmental issues," *Journal of industrial engineering and management studies*, vol. 8, no. 1, pp. 1–31, 2021.

[21] Z. Yu, M. Waqas, M. Tabish, M. Tanveer, I. U. Haq, and S. A. R. Khan, "Sustainable supply chain management and green technologies: a bibliometric review of literature," *Environmental Science and Pollution Research*, vol. 29, no. 39, pp. 58454–58470, 2022.

[22] G. Soni, S. Kumar, R. V. Mahto, S. K. Mangla, M. L. Mittal, and W. M. Lim, "A decision-making framework for Industry 4.0 technology implementation: the case of FinTech and sustainable supply chain finance for SMEs," *Technological Forecasting and Social Change*, vol. 180, Article ID 121686, 2022.

[23] P. Ghasemi, H. Hemmaty, A. Pourghader Chobar, M. R. Heidari, and M. Keramati, "A multi-objective and multi-level model for location-routing problem in the supply chain based on the customer's time window," *Journal of Applied Research on Industrial Engineering*, vol. 9, no. 3, pp. 203–230, 2022.

[24] Y. Shuang, A. Diabat, and Y. Liao, "A stochastic reverse logistics production routing model with emissions control policy selection," *International Journal of Production Economics*, vol. 213, pp. 201–216, 2019.

[25] A. Goli, E. B. Tirkolaee, and N. S. Aydın, "Fuzzy integrated cell formation and production scheduling considering automated guided vehicles and human factors," *IEEE Transactions on Fuzzy Systems*, vol. 29, no. 12, pp. 3686–3695, 2021.

[26] A. P. Chobar, M. A. Adibi, and A. Kazemi, "Multi-objective Hub-Spoke Network Design of Perishable Tourism Products Using Combination Machine Learning and Meta-Heuristic Algorithms," *Environment, Development and Sustainability*, pp. 1–28, 2022.

[27] T. Wu, H. Shen, and C. Zhu, "A multi-period location model with transportation economies-of-scale and perishable inventory," *International Journal of Production Economics*, vol. 169, pp. 343–349, 2015.

[28] İ. Çapar, "Joint shipment consolidation and inventory decisions in a two-stage distribution system," *Computers & Industrial Engineering*, vol. 66, no. 4, pp. 1025–1035, 2013.

[29] Y.-B. Park, J.-S. Yoo, and H.-S. Park, "A genetic algorithm for the vendor-managed inventory routing problem with lost sales," *Expert Systems with Applications*, vol. 53, pp. 149–159, 2016.

[30] S. M. Mousavi and R. Tavakkoli-Moghaddam, "A hybrid simulated annealing algorithm for location and routing scheduling problems with cross-docking in the supply chain," *Journal of Manufacturing Systems*, vol. 32, no. 2, pp. 335–347, 2013.

[31] K. Govindan, A. Jafarian, and V. Nourbakhsh, "Bi-objective integrating sustainable order allocation and sustainable supply chain network strategic design with stochastic demand using a novel robust hybrid multi-objective metaheuristic," *Computers & Operations Research*, vol. 62, pp. 112–130, 2015.

[32] S. Jahangiri, A. Pourghader Chobar, P. Ghasemi, M. Abolghasemian, and V. Mottaghi, "Simulation-based optimization: analysis of the emergency department resources

under COVID-19 conditions," *International Journal of Industrial and Systems Engineering*, vol. 1, no. 1, pp. 1–10, 2021.

[33] C. Rout, A. Paul, R. S. Kumar, D. Chakraborty, and A. Goswami, "Integrated optimization of inventory, replenishment and vehicle routing for a sustainable supply chain under carbon emission regulations," *Journal of Cleaner Production*, vol. 316, Article ID 128256, 2021.

[34] N. Ghaffari-Nasab, M. Ghazanfari, and E. Teimoury, "Hub-and-spoke logistics network design for third party logistics service providers," *International Journal of Management Science and Engineering Management*, vol. 11, no. 1, pp. 49–61, 2016.