Research Article

Designing a Medical Supply Chain Network Considering the Risk of Supply and Flexible Production in Two-Stage Uncertain Conditions

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In the green supply chain approach, all the links that are put together to provide a product or service are considered, and strategic and operational decisions are made to increase the efficiency and effectiveness of the entire chain. At the same time, the environmental effects should be minimized. In this research, a nonlinear mixed-integer multiobjective model is developed to design a green closed-loop supply chain for medical products. In this supply chain, the echelons include supplier, manufacturer, warehouse, and customer in the forward supply chain and collection centers, repair services, and disposal centers in the reverse supply chain. In the proposed model, four objectives of customer satisfaction, environmental effects, supply risk, and total costs of the supply chain were considered. The developed model is implemented in a supply chain of medical products, and after optimizing the model, the main results including location and capacity of facilities, planning for flexible production, purchase of materials, service and maintenance plan, product transfer, and inventory level are determined and analyzed.

1. Introduction

Nowadays, many companies are trying to improve their business processes to meet customer expectations and satisfaction and be able to compete successfully in competitive environments. In this regard, supply chain management is one of the interesting and important issues among academic researchers and industry managers [1]. These processes begin with preparing raw materials and end with customer satisfaction by providing final products to customers. With the emergence of the concept of supply chain management and its recognition as an important competitive advantage, supply chain management has become an integral part of strategic decisions in each market. Supply chain management includes planning and managing the production/ manufacture, transportation, and distribution of products, from the supply of raw materials to the delivery of finished products to customers [2]. In fact, supply chain management is looking for a solution to take these measures with the lowest cost as well as the highest productivity and efficiency in the face of a definite or uncertain environment.

Green supply chain management was introduced by the Michigan State University Industrial Research Association in 1996, which is a new management model for environmental protection [3, 4]. Studies show that supply chain management with emphasis on environmental protection has become one of the most critical issues for customers, shareholders, governments, employees, and global pressures.
A green supply chain often means reducing or not using harmful chemicals, which is a complete misconception because the parachain goes beyond this stage and considers all parts of an organization. In fact, the green supply chain is the result of linking economic goals with the organization’s environmental goals. Minciardi et al. (2006) have designed the green supply chain intending to reduce waste materials. Jamshidi et al. [5] designed the green supply chain to reduce total supply chain costs, including raw material supply costs, maintenance costs, and transportation costs, as well as reducing emissions of carbon dioxide, carbon monoxide, and nitrous oxide. Chaabane et al. [6] designed a sustainable supply chain with the aim of reducing the production of toxic gases by pollutants, and in their work, sustainability through life cycle applications was considered. References [7, 8] have developed a model for the inventory system of a perishable commodity in the green supply chain.

References [9, 10] examined the chain of a perishable product with a fixed life cycle by an inventory-routing approach. In studies [10–13], waste materials are also considered while in studies [14] in 2013 and [9], products must be used for a fixed life before they break down. References [15–17] considered inventory routing with demand uncertainty.

Pishvae et al. [18] have proposed a robust optimization model to consider the uncertainty of the closed-loop supply chain network design. They introduced a multilevel network that includes customers in the primary and secondary markets, collection, distribution, and disposal centers with limited capacity. There was uncertainty in the amount of returned products, demand for recycled products, and shipping costs. The model considers both recycling and landfill activities. Amin & Zhang [19] presented a closed-loop supply chain network model under uncertainty conditions. In this study, a network that includes manufacturing plants, customers, collection centers, and landfills was considered. The model includes two objective functions: minimizing costs and maximizing the use of environmentally friendly raw materials. Tehrani Soltani et al. (2015) designed a multiobjective, multiproduct, and multiperiod closed-loop supply chain.

References [20–22] proposed a mathematical model for a closed-loop supply chain with environmental effects.

Reference [23] presented a two-stage stochastic programming model for supply and production optimization in a revised logistic. Reference [24] developed an effective solution for a sustainable green supply chain network design model. Reference [25] presented a multiobjective model for a gold supply chain, considering the CO2 emissions. Reference [26] proposed a single stage to evaluate and optimize green supply chain performance in a closed-loop network.

Reference [27] proposed a two-dimensional mixed-integer programming model for the closed-loop network to minimize total cost and discontinuity delivery. Reference [28] has designed a MILP model to maximize the overall profitability of a closed network. References [29, 30] proposed a multiobjective model that is influenced by uncertain supply and demand. Reference [31] proposed a two-objective mathematical model for a pharmaceutical supply chain network design problem. The model helps to make several decisions about strategic issues, such as the opening of pharmaceutical manufacturing centers and distribution centers.

References [32–34] developed a MILP model for the design of the location/facility network. In the proposed model, CO2 emissions are achieved through the construction of network facilities, various production processes, and vehicle transportation. Reference [35] introduced a multi-cycle supply chain network design model in Turkey. Reference [36] developed a mixed-integer mathematical model for the network design of a pharmaceutical supply chain. The two objective functions of the presented model seek to minimize the total cost and the maximum unmet demand.

Reference [4] presented a green closed-loop supply chain model considering material discount conditions. The study included several periods and several products, and customer demand in the model was clearly defined. Reference [37] has provided an integer nonlinear programming model for supply chain network design with consideration of transportation cost reductions. A new hybrid algorithm called KAGA has been developed and implemented in the glass industry to optimize this mathematical model.

Reference [38] has designed a stable closed-loop supply chain for water reservoirs. For this purpose, a robust fuzzy optimization model has been developed. Sensitivity analysis is also performed on essential parameters of the mathematical model, and the results are evaluated.

Reference [39] designed a novel, reusable, half-face respirator in case conventional medical supply chain failed to meet demand. The authors provided a new collaboration between the hospital, physicians, medical school, and school of engineering. Reference [40] has developed a stochastic planning model for closed-loop supply chain network design. To optimize this model, the whale optimization algorithm (WOA) and particle swarm optimization (PSO) have been used as popular methods. In addition to this development, genetic algorithm (GA) and simulated annealing (SA) have been used as well-known meta-heuristics for a comprehensive comparison.

After careful consideration of reviewed research items, the main contribution and the novelty of this paper can be summarized as follows:

(i) Incorporating the green supply chain network design for medical supply chain.

(ii) Optimizing all the fixed and variable costs, amount of carbon dioxide produced in the supply chain, costs of customer dissatisfaction, and total risk of the supply chain simultaneously.

(iii) Analyzing the effect of environmental issues in the green supply chain under different scenarios.

2. Methodology

Considering the issues raised in the field of the green supply chain, the main purpose of this study is to continue the research conducted by other researchers who, leaving aside some of the assumptions that facilitate and limit supply
chain issues, present their proposed models. The problem should be developed in such a way that its assumptions are more compatible with real-world conditions, so the purpose of this study is to develop a multiobjective green supply chain model that includes supplier, manufacturer, and customer levels in the forward supply chain and collection, recycling, and disposal centers in the reverse supply chain.

In this study, the raw material supplier utilized quantitative discount assumptions to inspect the influence of these tactical decisions on the architecture of the green supply chain network. The proposed model’s goals include minimizing overall network costs, CO2 emissions, customer discontent, and material supply risk.

2.1. Model Assumptions. We propose a multiproduct, multiperiod, and multiobjective green closed-loop supply chain network design model. Available locations for production, recovery, distribution, and collection centers are available.

(i) Customers’ demands are different, and they must be completely satisfied in each period.
(ii) Suppliers and supply risk are considered.
(iii) Customer dissatisfaction is considered based on a lack of response to the demand.
(iv) Inventory holding costs are considered for production, distribution, and collection centers.
(v) The amount of discount in each supplier and the minimum order quantity are known.
(vi) Factory facilities (production site), warehouses, and collection centers all have specific capacities.
(vii) The two main sources of raw materials are supplied by suppliers: green and nongreen raw materials.
(viii) In each period, only one supplier can be selected to supply each item. The discount amount applies to all products.

Considering the above assumptions, the important decisions that are made in the proposed mathematical model are as follows:

(i) Determining the locations of new facilities.
(ii) Assigning customers to facilities.
(iii) Determining shipping mode.
(iv) Determining the capacity level of each facility.
(v) Determining the quantity of raw materials purchased from suppliers.

(vi) Determining the amount of production in production centers.
(vii) Determining the inventory level of products in production, distribution, and collection centers.
(viii) Determining the amount of flow shipped between network facilities.

2.2. Mathematical Model. In this research, a four-echelon closed-loop supply chain network is considered. The forward network includes suppliers of semifinished products, production centers, warehouses (which store and deliver the products to customers), and customers. The reverse network also includes the collection centers, repair centers, and disposal centers.

In the forward flow path, the supplier sends the required semifinished product to the warehouses. After assembly, the parts are sent to the warehouse for sale in production centers. After receiving products from production centers, distribution centers (warehouses) send them to the customers. The customer submits initial service request (overhaul) to return the product, and the product is sent to the repair center (factory) by the collection center. In the repair center, after inspecting the products, those products that can be repaired are sent to the distribution centers (warehouse) after repair, and then the overhauled device is returned to its specific customer.

2.3. Sets, Parameters, and Decision Variables. According to the objectives, assumptions, and characteristics of the problem, for the proposed model, sets, parameters, and decision variables were defined as follows. Decision variables

2.4. Mathematical Model Formulation. The proposed mathematical model is divided into two sections, the first of which contains the objective functions and the second of which contains the constraints. In the section of objective functions, f1 denotes all fixed and variable costs (creating facilities, costs of processes in each facility, and moving between facilities), f2 is the amount of carbon dioxide produced in the supply chain flow due to processes and transfers between the facility and the delivery of products to customers, f3 represents the costs of customer dissatisfaction with the company, and f4 minimizes the total risk of the supply chain. (Table 1)

\[
\begin{align*}
\text{Min} \ f_1 &= C1 + C2 + C3 + C4, \\
C1 &= \sum_{f \in F} f_j x_j + \sum_{w \in W} f''_w x''_w + \sum_{i \in I} f'''_i x'''_i,
\end{align*}
\]
Table 1: Model decision variables.

| Decision variables | Description |
|--------------------|-------------|
| $f$                | Factories   | ($f = 1, 2, \ldots, F$) |
| $w$                | Warehouses  | ($w = 1, 2, \ldots, W$) |
| $c$                | Customers   | ($c = 1, 2, \ldots, C$) |
| $i$                | Collection centers | ($i = 1, 2, \ldots, I$) |
| $t$                | Planning courses | ($t = 1, 2, \ldots, T$) |
| $s$                | Intended scenarios in the model | ($s = 1, 2, \ldots, S$) |
| $p$                | Supplier products | ($su = 1, 2, \ldots, SU$) |
| $b$                | Piece/raw material | ($b = 1, 2, \ldots, B$) |
| $tsu$              | Supplier relocation options (vehicle) | ($tsu = 1, 2, \ldots, TSU$) |
| $tw$               | Options for moving between warehouses | ($tw = 1, 2, \ldots, TW$) |
| $tk$               | Customer transferring options (vehicle) | ($tk = 1, 2, \ldots, TK$) |
| $ti$               | Displacement options between disassembly centers | ($ti = 1, 2, \ldots, TI$) |
| $tf$               | Factory transferring options (vehicle) | ($tf = 1, 2, \ldots, TF$) |
| $d_{f,c,p,t}$      | Customer demand in each scenario for each product |
| $B_{Cw,b}$         | Market prices for each supplier in each scenario |
| $voff_{su,b}$      | Purchase volume to offer a discount for each supplier |
| $CS_{su,b}$        | Part supply capacity for each supplier |
| $BO_{p,b}$         | Maximum discount available |
| $HVM_{su,i}$       | Material supply risk from the supplier |
| $Risk_{su,i}$      | Cost of shortage dissatisfaction |
| $SC_{ic}$          | Probability of occurrence of scenario $s$ |
| $pc_i$             | Cost of moving a unit of products from factory $f$ to warehouse $w$ |
| $t1_{f,w}$         | Cost of moving a unit of products from the warehouse $w$ to the customer $c$ |
| $t2_{w,s}$         | Cost of transportation in order to collect products and transfer them from customer $c$ to disassembly center $i$ |
| $t3_{c}$           | Cost of moving a unit of products in order to transfer it from the collection dismantling center $i$ to the factory $f$ |
| $t4_{su,f}$        | Cost of moving a unit of products in order to transfer it from the supplier center $su$ to the warehouse $w$ |
| $t5_{su,w}$        | Rates of transportation of products from factory $f$ to warehouse $w$ |
| $t6_{w,c}$         | Rates of transportation of products from the warehouse $w$ to the customer $c$ |
| $t7_{f,c}$         | Product collection rate and transfer from customer $c$ to disassembly center $i$ |
| $t8_{f,c}$         | Rate of transportation of products from the collection dismantling center $i$ to the factory $f$ |
| $t9_{f,c}$         | Rates of transportation of products from the supplier $su$ to the warehouse $w$ |
| $t10_{su,w}$       | Distance between factory $f$ and warehouse $w$ |
| $t11_{w,c}$        | Distance between warehouse $w$ and customer $c$ |
| $t12_{c,i}$        | Distance between customer $c$ and disassembly center $i$ |
| $t13_{c,f}$        | Distance between collection dismantling center $i$ and factory $f$ |
| $t14_{w,c}$        | Distance between supplier and warehouse |
| $t15_{c,f}$        | Fixed cost for factory reconstruction $f$ |
| $t16_{su}$         | Fixed cost for warehouse reconstruction $w$ |
| $t17_{f,c}$        | Fixed cost for reconstruction of the collection dismantling center $i$ |
| $t18_{f,c}$        | Variable cost of production per unit of product $p$ in factory $f$ |
| $t19_{w,c}$        | Variable cost of production per unit of product $p$ in stock $w$ |
| $t20_{c}$          | Variable cost of collecting returned products $p$ of customer $c$ |
| $t21_{f,c}$        | Maximum factor production capacity $f$ to produce product $p$ |
| $t22_{w,c}$        | Maximum warehouse processing capacity $w$ for product warehouse $p$ |
| $t23_{c,f}$        | Maximum factor reconstruction capacity $f$ for product $p$ |
| $t24_{w,c}$        | Maximum storage capacity $w$ to hold part $b$ |
| $q_{f,p}$          | The lowest percentage of each unit of parts returned by a customer (product) |
| $q_{w,p}$          | Minimum percentage of product units to be shipped from a disassembly center |
| $e1_{f,p}$         | The amount of carbon dioxide released per unit of product produced at the plant $f$ |
| $e2_{w,p}$         | The amount of carbon dioxide released per shipment per unit of stock $w$ |
| $e3_{c,i}$         | The amount of carbon dioxide released per disassembly of each product unit at the center $i$ |
| $e4_{f,p}$         | The amount of carbon dioxide released per unit of product regenerated at the factory $f$ |
| $e5_{w,b}$         | The amount of carbon dioxide released per shipment for per unit $b$ in storage $w$ |
Table 1: Continued.

| Expression | Description |
|------------|-------------|
| ct1_{f}   | The amount of carbon dioxide released to move products between factory \( f \) and warehouse \( w \) with vehicle \( f \) |
| ct2_{w}   | The amount of carbon dioxide released to move products between warehouse \( w \) and customer \( c \) by a \( tw \)-type vehicle |
| ct3_{k}   | The amount of carbon dioxide released to move the product between customer \( c \) and the disassembly center \( i \) with vehicle \( tk \) |
| \( t4_{ti} \) | The amount of carbon dioxide released to move products between the collection dismantling center \( i \) and plant \( f \) by vehicle \( ti \) |
| ct5_{su}  | The amount of carbon dioxide released to move the part between the warehouses \( w \) and the suppliers \( su \) with vehicle \( tsu \) |
| \( k_{b} \) | Precautionary storage of parts |
| \( \delta_{su,w,b,s} \) | Number of pieces \( b \) purchased from supplier \( su \) and transferred to warehouse \( w \) by vehicle \( tsu \) in scenario \( s \) and period \( t \) |
| \( \delta_{w,s} \) | Number of pieces \( b \) sent from warehouse \( w \) to factory using vehicle \( tw \) in scenario \( s \) and in period \( t \) |
| \( \alpha_{w,s} \) | Number of products \( p \) produced from factory \( f \) and transferred to warehouse \( w \) using vehicle \( tf \) in scenario \( s \) and in period \( t \) |
| \( \beta_{w,c,p,s,t} \) | Number of products \( p \) produced from warehouse \( w \) to customer \( c \) using vehicle \( tw \) in scenario \( s \) and period \( t \) |
| \( \delta_{tk,i,c,p,s,t} \) | The number of products \( p \) collected from customer \( c \) to the disassembly center \( i \) in scenario \( s \) and in period \( t \) |
| \( \gamma_{ci,p,s,t} \) | The number of products \( p \) disassembled that are transferred from center \( i \) to factory \( f \) using vehicle \( ti \) in scenario \( s \) and in period \( t \) |
| \( I_{w,b,s,t} \) | Inventory \( w \) for each piece \( b \) in period \( t \) in scenario \( s \) |
| \( \theta_{f,w,p,s} \) | Number of products \( p \) for each customer \( c \) in each period \( t \) and for each scenario \( s \) |
| \( \beta_{w,c,p,s,t} \) | Cost of parts purchased in different periods from suppliers |
| \( \delta_{t,s} \) | Total discounts received from purchases in different periods |
| \( \theta_{f,w,p,s} \) | Percentage of discounts offered by suppliers for each type of piece in each period and scenario |
| \( \gamma_{ti,w,b,s,t} \) | 1 when factory \( f \) is active and 0 otherwise |
| \( \gamma_{ti,w,b,s,t} \) | 1 when warehouse \( w \) is active and 0 otherwise |
| \( \gamma_{ti,w,b,s,t} \) | 1 when center \( i \) is active and 0 otherwise |

\[
C2 = \sum_{s \in S} \sum_{f \in F} \sum_{p \in P} v1_{f,p} \times \sum_{w \in W} \sum_{t \in TF} \alpha_{f,w,p,s,t} + \sum_{s \in S} \sum_{l \in I} \sum_{i \in T} \gamma_{l,c,i,p,s,t} + \sum_{s \in S} \sum_{p \in P} \sum_{t \in I} v3_{c,i,p,t} + \sum_{s \in S} \sum_{c \in C} \sum_{t \in TK} \gamma_{c,i,p,s,t} \tag{3}
\]

\[
C3 = \sum_{s \in S} \sum_{f \in F} \sum_{p \in P} \sum_{w \in W} \sum_{t \in TF} t1_{f,w} \times \alpha_{f,w,p,s,t} + \sum_{s \in S} \sum_{l \in I} \sum_{i \in T} t2_{l,c,i} \times \gamma_{l,c,i,p,s,t} + \sum_{s \in S} \sum_{c \in C} \sum_{t \in TK} \gamma_{c,i,p,s,t}
\]

\[
C4 = \sum_{s \in S} \sum_{w \in W} \sum_{p \in P} \sum_{c \in C} \sum_{t \in TF} r1_{s,b,t,c,w,s} \tag{4}
\]

\[
\min f_2 = ERP + EHA + EDC + ERM + ETR, \tag{5}
\]

\[
EPR = \sum_{f \in F} e1_{f} \sum_{w \in W} \sum_{t \in TF} \alpha_{f,w,p,s,t} \tag{6}
\]

\[
EHA = \sum_{w \in W} e2_{w} \sum_{c \in C} \sum_{t \in TW} \beta_{w,c,p,s,t} \tag{7}
\]

\[
EDC = \sum_{c \in C} e3_{c} \sum_{l \in I} \sum_{t \in TK} \gamma_{l,c,i,p,s,t} \tag{8}
\]

\[
ER = \sum_{f \in F} e4_{f} \sum_{w \in W} \sum_{t \in TF} \beta_{f,w,p,s,t}\]
the total cost of carbon dioxide emissions in the raw parts needed to manufacture the products. TransportationCost (C3), costs incurred due to handling and transferring; and TotalBuyingCost (C4), costs of purchasing the parts needed to manufacture the products.

The second objective function in (6)–(11) contains the total cost of carbon dioxide emissions in the raw materials, which is demonstrated with EPR, in production (EHA), in holding and transferring (EDC), and in collecting (ERM). Moreover, the carbon dioxide emissions due to reconstructions and transportation are shown with ETR. In the third objective function (12), the total costs that enter the system due to customer dissatisfaction are minimized. In the fourth objective function (13), the total costs due to the risk of raw material supply are minimized.

\[
ER = \sum_{i=1}^{n} e^{4i} \sum_{j=1}^{n} \theta_{ij}^{4i} 
\]

\[
ETR = \sum_{t \in TF} e^{1t} \sum_{p \in P \in f \in F} \sum_{w \in W} e^{1f, f \in F} \times m^{1f, f \in F} + \sum_{t \in TW} e^{2tw} \sum_{p \in W \in c \in C} e^{2tw} \times m^{2tw} \times p^{tw} \times m^{3tw} \times \gamma_{c, p, t}^{3tw} + \sum_{t \in TF} e^{4ti} \sum_{p \in P \in f \in F} \sum_{w \in W} e^{4ti} \times m^{4ti} \times \theta_{ij}^{4ti} + \sum_{t \in TW} e^{5tw} \sum_{p \in P \in f \in F} \sum_{w \in W} e^{5tw} \times m^{5tw} \times \delta^{5tw} \times \delta_{w, b, s, t}^{5tw}
\]

\[
\min f_3 = \sum_{s \in S} p_s \sum_{c \in C} \sum_{p \in P \in T} SC_{s, c} \times SGF_{c, p, t}
\]

\[
\min f_4 = \sum_{s \in SU} \sum_{w \in SU} Wz_{w, s} \times \text{Risk}_{w, s}
\]

As mentioned earlier, the total cost in (1)–(5) consists of TotalFixedCost (C1) or fixed costs incurred throughout the chain from supplier to customer; TotalVariableCost (C2), which is the sum of the variable costs of the chain; TotalTransportationCost (C3), costs incurred due to handling and transfers; and TotalBuyingCost (C4), costs of purchasing the parts needed to manufacture the products.

\[
\sum_{w \in W} \sum_{t \in TF} \alpha_{f, w, p, s, t}^{tf} \leq Ca_{f, p} \times x_{f, s} \forall f \in F, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{f \in F} \sum_{t \in TF} \alpha_{f, w, p, s, t}^{tf} \leq Cb_{w, p} \times x_{w, b} \forall w \in W, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{c \in C} \sum_{t \in TW} \beta_{w, c, p, s, t}^{cw} \leq \sum_{f \in F} \sum_{t \in TF} \alpha_{f, w, p, s, t}^{tf} \forall w \in W, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{w \in W} \sum_{t \in TW} \beta_{w, c, p, s, t}^{cw} \leq d_{c, p, s} \forall c \in C, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{i \in I} \sum_{t \in TK} \gamma_{c, i, p, s, t}^{ik} \leq d_{c, i, s, t} \forall c \in C, \quad t \in T, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{i \in I} \sum_{t \in TK} \gamma_{c, i, p, s, t}^{ik} \geq q_{d, p} \times d_{c, i, s, t} \forall c \in C, \quad p \in P, \quad s \in S, \quad t \in T,
\]

\[
\sum_{w \in W} \sum_{t \in TW} \theta_{w, b, s, t}^{iw} \geq q_{b} \times \sum_{i \in I} \sum_{t \in TK} \gamma_{c, i, p, s, t}^{ik} \times b_{o, p} \forall w \in W, \quad p \in P, \quad b \in B, \quad s \in S, \quad t \in T,
\]

\[
\sum_{t \in TW} \theta_{w, b, s, t}^{iw} + \sum_{s \in SU} \sum_{w \in SU} \delta_{w, b, s, t}^{iw} \leq Cm_{w, b} \times x_{w, s} \forall w \in W, \quad b \in B, \quad s \in S, \quad t \in T,
\]
In (14), any quantity of product \( p \) which is considered for transfer from any factory \( f \) to any warehouse \( w \) through any transport option \( tf \) must be less than or equal to the maximum capacity of the relevant factory. In (15), the total number of units of product to be stored in the warehouse through each shipping option must be less than or equal to the maximum warehouse capacity. In (16), the total number of product units from one warehouse to each customer exported through each shipping option must be less than or equal to the total amount of product units that enter the relevant warehouse from each factory through each shipping option.
Moreover, in (17), the total number of product units distributed from each warehouse through shipping options to meet customer demand must be greater than or equal to that customer demand. Equation (18) considers the total number of product units that must be collected from the customer and transported to an assembly center with a shipping option, which must be less than the capacity of the relevant center. Equation (20) also limits the total number of product units that must be shipped via each shipping option from one customer to each DC and must be greater than or equal to the minimum percentage of product returns from the total number of relevant customers’ requests. In (21), the total number of product units that are sent from each assembly center to each factory through each shipping option must be greater than or equal to the minimum percentage of product units, which must be greater than the total number of product units imported to the assembly center.

In (22), the total number of units of the product that can be produced, which must be sent from each assembly center to a factory by any means of transportation, must be less than or equal to the maximum reproduction capacity of the relevant factory. Equation (23) specifies the minimum raw materials required to manufacture and supply the products required by the market. Equation (24) specifies the parts required to manufacture products according to the list of parts, and according to that, the parts are transferred to the production unit. In (25), the quantity of each type of part sent to the production unit must be less than the amount purchased for that type of part.

Equations (26) and (32) specify which supplier has offered a discount on the purchase of the part. Equation (27) calculates the cost of purchasing parts, considering account discounts. Equation (28) calculates the number of discounts received by the company. Equation (29) states that the cost of purchasing parts must be positive. In (30), each supplier has a limit for offering discounts, which applies to the conditions of suppliers in offering discounts. Equation (31) specifies that the percentage of discounts must be negative.

Equations (32) and (35) calculate the supply risk, and Equation (33) calculates the inventory of products in each period and each scenario. Equation (34) calculates inventory of parts in each period and each scenario. Equation (35) is related to supply risk calculations. Buying a large number is riskier. Since each supplier has the capacity or may supply a certain number of products based on profit and loss, it is necessary to consider some risks for the supply of materials. This equation calculates the supply risk of the component assembly. In (36), it is noted that the risk level of suppliers should not be more than a certain limit. Equation (37) calculates the level of customer dissatisfaction due to nonresponse to needs. Equation (38) keeps the stock of inventory parts above the contingency reserve. This issue is examined in each period and scenario. Equation (39) guarantees the values greater than zero for the variables of transmission volume in the network, and (40) also specifies binary values for the establishment of facilities (factories, warehouses, and collection centers).

2.5. Solution Procedure. The general form of a multiobjective problem is as follows:

$$\text{Max } f_1(x), f_2(x), f_3(x), \ldots, \quad (41)$$

$$\text{s.t.: } x \in S,$$

where \( x \) is the vector of the decision variables; \( f_1(x), f_2(x), \) and \( f_3(x) \) are the objective functions; and \( S \) is the answer space. In the weighting method, the objective functions are usually scaled first, and then each weight is assigned a weight. The general form of the weighting method to solve the problem is as follows:

$$\text{Max } ZW = \sum_{i=1}^{p} w_i f_i(x), \quad (42)$$

$$0 \leq w_i \leq 1,$$

$$\sum_{i=1}^{p} w_i = 1, \quad (43)$$

where the weight of each of the objective functions is predetermined, and the optimal value of each of the objective functions can be found by using single-objective optimization. In order to better demonstrate the solution procedure, the steps of optimizing the proposed mathematical model are provided in Figure 1.

3. Numerical Results

Based on the amount of customer demand and, in the other dimension, the ability to provide funding or lack of demand, the warehouse and production space are selected, and then production planning and inventory control are specified. According to the model’s assumptions, each customer must have received their demand. For example, in the first scenario, the first customer has a demand for the first product, and in the second scenario, there is a demand for the second product. The supply chain is being planned to meet the demand, and the manufactured products are sent from warehouses. Moreover, the number of first type products sent from the first warehouse is equal to the total inputs of this product from the factory to the warehouse, and also according to the list of parts, parts have been purchased. Details of purchasing parts, parts sent to production, products produced, products sent to customers, returned products, and repaired products are as shown in Tables 2–7.

As mentioned earlier, two-stage stochastic programming is applied, and the best solution based on the conditions of the scenarios and their probabilities is obtained. Accordingly, we would decide whether to open or close a facility based on the characteristics of each scenario, but in two-stage programming, a decision is first made on the nature of
Table 2: Values of the parameter $\delta_{su,w,b,s,t}^{su}$.

| Supplier | Warehouse | Type of transport | Type of piece | Scenario | Periods | PerIOD 1 | Period 2 | Period 3 | Period 4 | Period 5 |
|----------|-----------|-------------------|---------------|----------|---------|----------|----------|----------|----------|----------|
| su1-RO   | First warehouse | Vehicle type 2  | b 1-P         | 1        | 3       | 0        | 6        | 3        | 4        | 4        |
| su1-RO   | First warehouse | Vehicle type 2  | b 1-P         | 2        | 6       | 9        | 2        | 0        | 5        | 5        |
| su1-RO   | First warehouse | Vehicle type 2  | b 2-V         | 2        | 6       | 4        | 5        | 4        | 6        | 6        |
| su1-RO   | First warehouse | Vehicle type 2  | b 3-M         | 2        | 3       | 1        | 8        | 4        | 5        | 5        |
| su1-RO   | First warehouse | Vehicle type 2  | b 3-M         | 1        | 2       | 5        | 2        | 2        | 3        | 3        |
| su1-RO   | Second warehouse | Vehicle type 2  | b 1-P         | 2        | 7       | 7        | 1        | 2        | 0        | 0        |
| su1-RO   | Second warehouse | Vehicle type 2  | b 1-P         | 1        | 2       | 4        | 7        | 2        | 8        | 8        |
| su1-RO   | Second warehouse | Vehicle type 2  | b 2-V         | 2        | 9       | 2        | 1        | 4        | 4        | 6        |
| su1-RO   | First warehouse | Vehicle type 2  | b 3-M         | 1        | 10      | 8        | 9        | 2        | 0        | 0        |

Table 3: Values of the parameter $\omega_{tw,w,f,b,s,t}^{su}$.

| Warehouse | Factory | Type of transport | Type of piece | Scenario | Periods | PerIOD 1 | Period 2 | Period 3 | Period 4 | Period 5 |
|-----------|---------|-------------------|---------------|----------|---------|----------|----------|----------|----------|----------|
| First warehouse | First factory | Vehicle type 2  | b 3-M         | 1        | 1       | 3        | 3        | 10       | 8        | 8        |
| First warehouse | First factory | Vehicle type 2  | b 1-P         | 2        | 3       | 1        | 2        | 10       | 8        | 8        |
| First warehouse | First factory | Vehicle type 2  | b 1-P         | 1        | 4       | 10       | 1        | 8        | 4        | 4        |
| First warehouse | First factory | Vehicle type 2  | b 2-V         | 2        | 8       | 1        | 6        | 5        | 7        | 7        |
| First warehouse | First factory | Vehicle type 2  | b 2-V         | 1        | 1       | 9        | 1        | 0        | 4        | 4        |
| First warehouse | First factory | Vehicle type 2  | b 3-M         | 2        | 0       | 6        | 8        | 3        | 6        | 6        |
| First warehouse | First factory | Vehicle type 2  | b 3-M         | 1        | 0       | 10       | 5        | 8        | 9        | 9        |
| First warehouse | First factory | Vehicle type 2  | b 1-P         | 2        | 2       | 10       | 5        | 1        | 5        | 5        |
| Second warehouse | First factory | Vehicle type 2  | b 2-V         | 1        | 10      | 6        | 8        | 9        | 3        | 3        |
| Second warehouse | First factory | Vehicle type 2  | b 3-M         | 2        | 6       | 8        | 7        | 3        | 3        | 3        |
| Second warehouse | First factory | Vehicle type 2  | b 1-P         | 1        | 1       | 5        | 3        | 4        | 5        | 5        |
| Second warehouse | First factory | Mean type 2    | b 1-P         | 2        | 5       | 1        | 8        | 4        | 2        | 2        |
| Second warehouse | First factory | Vehicle type 2  | b 2-V         | 1        | 3       | 9        | 6        | 7        | 4        | 4        |
| Second warehouse | First factory | Vehicle type 2  | b 2-V         | 2        | 7       | 7        | 8        | 0        | 4        | 4        |
| Second warehouse | First factory | Vehicle type 2  | b 3-M         | 1        | 6       | 5        | 2        | 0        | 1        | 1        |
| Second warehouse | First factory | Vehicle type 2  | b 3-M         | 2        | 1       | 7        | 0        | 4        | 2        | 2        |
| Factory   | Warehouse       | Type of transport | Product type | Scenario | Periods | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 |
|-----------|-----------------|-------------------|--------------|----------|---------|----------|----------|----------|----------|----------|
| First factory | First warehouse | Vehicle type 1   | First product | 1        |         | 3        | 3        | 9        | 10       | 5        |
| First factory | First warehouse | Vehicle type 1   | First product | 2        |         | 2        | 10       | 1        | 9        | 4        |
| First factory | First warehouse | Vehicle type 1   | Second product | 1        |         | 3        | 8        | 7        | 4        | 4        |
| First factory | First warehouse | Vehicle type 1   | Second product | 2        |         | 1        | 2        | 6        | 7        | 4        |
| First factory | Second warehouse| Vehicle type 1   | First product | 1        |         | 0        | 1        | 7        | 7        | 8        |
| First factory | Second warehouse| Vehicle type 1   | Second product | 2        |         | 9        | 5        | 8        | 4        | 6        |
| First factory | Second warehouse| Vehicle type 1   | Second product | 1        |         | 8        | 7        | 5        | 2        | 0        |

**Table 5: Values of the parameter $\beta_{w,c,p,s,t}^w$.**

| Warehouse       | Customer        | Type of transport | Product type | Scenario | Periods | First | Second | Third | Fourth | Fifth |
|-----------------|-----------------|-------------------|--------------|----------|---------|-------|--------|-------|--------|-------|
| First warehouse | First customer  | Vehicle type 2    | First product | 1        |         | 9     | 9      | 8     | 8      | 5     |
| First warehouse | First customer  | Vehicle type 2    | Second product | 2        |         | 7     | 2      | 3     | 5      | 9     |
| First warehouse | Second customer | Vehicle type 2    | First product | 1        |         | 3     | 3      | 0     | 10     | 8     |
| First warehouse | Third customer  | Vehicle type 2    | First product | 2        |         | 4     | 1      | 8     | 5      | 9     |
| First warehouse | Third customer  | Vehicle type 2    | Second product | 1        |         | 0     | 9      | 9     | 0      | 5     |
| Second warehouse| Fourth customer | Vehicle type 2    | First product | 2        |         | 3     | 3      | 10    | 0      | 10    |
| Second warehouse| Fourth customer | Vehicle type 2    | Second product | 1        |         | 9     | 0      | 7     | 2      | 9     |
| Second warehouse| Fourth customer | Vehicle type 2    | First product | 2        |         | 6     | 4      | 1     | 3      | 8     |
| Second warehouse| Fourth customer | Vehicle type 2    | Second product | 2        |         | 0     | 1      | 8     | 0      | 4     |
| Second warehouse| Fourth customer | Vehicle type 2    | First product | 1        |         | 10    | 2      | 6     | 1      | 0     |
| Second warehouse| Fourth customer | Vehicle type 2    | Second product | 2        |         | 3     | 5      | 3     | 8      | 5     |
| Second warehouse| Fourth customer | Vehicle type 2    | Second product | 1        |         | 2     | 0      | 8     | 8      | 0     |
| Second warehouse| Fourth customer | Vehicle type 2    | Second product | 2        |         | 5     | 2      | 5     | 6      | 0     |

**Table 6: Values of the parameter $\gamma_{k,c,p,s,t}^k$.**

| Customer        | Separation center | Type of transport | Product type | Scenario | Periods | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 |
|-----------------|-------------------|-------------------|--------------|----------|---------|----------|----------|----------|----------|----------|
| First customer  | First capital     | Vehicle type 1    | Second product | 1        |         | 4       | 3        | 9       | 6        | 10       |
| First customer  | First capital     | Vehicle type 1    | Second product | 2        |         | 5       | 3        | 0       | 2        | 1        |
| Second customer | First capital     | Vehicle type 2    | First product | 1        |         | 8       | 3        | 6       | 1        | 4        |
| Second customer | First capital     | Mean type 2       | First product | 2        |         | 10      | 4        | 2       | 10       | 8        |
| Fourth customer | First capital     | Vehicle type 1    | First product | 1        |         | 4       | 3        | 0       | 1        | 0        |
| Fourth customer | First capital     | Vehicle type 1    | Second product | 2        |         | 6       | 2        | 5       | 2        | 4        |
| Fourth customer | First capital     | Vehicle type 1    | Second product | 1        |         | 2       | 3        | 4       | 3        | 10       |
| Fourth customer | First capital     | Vehicle type 1    | Second product | 2        |         | 9       | 6        | 10      | 6        | 2        |

**Table 7: Values of the parameter $\theta_{i,w,h,s,t}^i$.**

| Separation center | Warehouse       | Type of transport | Type of returned piece | Scenario | Periods | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 |
|-------------------|-----------------|-------------------|------------------------|----------|---------|----------|----------|----------|----------|----------|
| First capital     | First warehouse | Vehicle type 1    | B1–P                   | 1        |         | 0        | 1        | 0        | 0        | 0        | 6        |
| First capital     | First warehouse | Vehicle type 1    | B1–P                   | 2        |         | 0        | 3        | 1        | 0        | 0        | 7        |
| First capital     | First warehouse | Vehicle type 1    | B2–V                   | 1        |         | 0        | 0        | 2        | 0        | 0        | 10       |
| First capital     | First warehouse | Vehicle type 1    | B2–V                   | 2        |         | 0        | 3        | 0        | 4        | 0        | 10       |
| First capital     | First warehouse | Vehicle type 1    | B3–M                   | 1        |         | 0        | 3        | 1        | 0        | 0        | 30       |
| First capital     | First warehouse | Vehicle type 1    | B3–M                   | 2        |         | 2        | 1        | 3        | 0        | 29       |
the facility, and then we respond to the customer’s request based on the available facility. The results in 2 different scenarios are shown in Table 8.

In the following, we compare the proposed model in two definite and solid cases (per nominal data) and then examine the sensitivity analysis of the model shown in Table 9.

Both certain and stochastic models have been solved using GAMS optimization software and a computer with Core i7 and 6G RAM. The average and variance of customer demand in both cases are shown in Table 10.

Moreover, the demand of customers in each scenario is shown in Table 11.

Table 8: Details of the model optimization in multiscenario mode.

| Cost                  | Scenario 1 | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Period 7 |
|-----------------------|------------|----------|----------|----------|----------|----------|----------|----------|
| Fixed cost ($)        |            | 160      | 155      | 143      | 147      | 159      | 143      | 170      |
| Variable cost ($)     |            | 153      | 172      | 265      | 193      | 154      | 116      | 169      |
| CO2 emission cost ($) |            | 230      | 265      | 293      | 186      | 215      | 168      | 216      |
| Total risk ($)        |            | 242      | 273      | 316      | 189      | 219      | 193      | 221      |

| Scenario 2 | 2214   | 2107   | 2166   | 1995   | 2405   | 2256   | 2364   |
| Scenario 2 | 1949   | 2303   | 2151   | 1955   | 2091   | 2271   | 2015   |

| Scenario 2 | 0.37   | 0.37   | 0.39   | 0.34   | 0.34   | 0.38   | 0.39   |
| Scenario 2 | 0.42   | 0.47   | 0.53   | 0.48   | 0.46   | 0.47   | 0.45   |

Table 9: Solution of different model scenarios and comparison between them.

| Step | State               | Scenario | Probability of each scenario | Total fixed and changing costs | Total costs of carbon dioxide | Total deficit costs | Total supply risk costs |
|------|---------------------|----------|------------------------------|-------------------------------|-------------------------------|---------------------|------------------------|
| 1    | Uncertain planning  | 2        | 0.6                          | 9389                          | 867058                        | 0                   | 1.220                  |
| 2    | Uncertain planning  | 2        | 0.4                          | 10481                        | 1221826                       | 0                   | 1.400                  |
| 3    | Certain planning    | 1        | 0.6                          | 8669                         | 867195                        | 0                   | 1.310                  |
| 4    | Certain planning    | 2        | 0.4                          | 10481                        | 1221826                       | 0                   | 1.400                  |

Table 10: Customer demand in each period and each scenario for each product.

| Scenario                | First product | Second product |
|-------------------------|---------------|----------------|
| Economic stability      | 1             | 0.39           | 0.6            |
| Irregularities in prices and economic instability | 1             | 0.39           | 0.43           |

Table 11: Customers demand in each period and each scenario for each product.

| Customers | Period | Scenario | First product | Second product | Customers | Period | Scenario | First product | Second product |
|-----------|--------|----------|---------------|----------------|-----------|--------|----------|---------------|----------------|
| c1        | 1      | s1       | 1             | 0              | c3        | 2      | s1       | 1             | 0              |
| c1        | 1      | s2       | 1             | 1              | c3        | 2      | s2       | 2             | 0              |
| c1        | 5      | s1       | 0             | 1              | c3        | 4      | s1       | 1             | 0              |
| c1        | 5      | s2       | 2             | 1              | c3        | 4      | s2       | 2             | 0              |
| c2        | 1      | s1       | 1             | 0              | c3        | 5      | s1       | 1             | 0              |
| c2        | 1      | s2       | 2             | 0              | c3        | 5      | s2       | 1             | 0              |
| c2        | 2      | s1       | 1             | 0              | c4        | 1      | s1       | 1             | 1              |
| c2        | 3      | s1       | 1             | 0              | c4        | 2      | s1       | 0             | 1              |
| c2        | 3      | s2       | 1             | 0              | c4        | 2      | s2       | 1             | 1              |
| c2        | 4      | s1       | 1             | 0              | c4        | 3      | s1       | 1             | 0              |
| c2        | 5      | s1       | 1             | 0              | c4        | 3      | s2       | 1             | 0              |
| c2        | 5      | s2       | 1             | 0              | c4        | 5      | s1       | 0             | 1              |
| c3        | 1      | s1       | 0             | 1              | c4        | 5      | s2       | 1             | 1              |
| c3        | 1      | s2       | 0             | 1              | -          | -      | -        | -             | -              |
| c3        | 1      | s2       | 0             | 1              | -          | -      | -        | -             | -              |
According to Figure 4, the increase in the fourth objective function occurs due to occurrence in the supply chain. The fewer suppliers of raw materials, the more purchases of parts for manufacturing and production. Also, supplying more materials from one supplier and reducing costs are more cost-effective than increasing risk due to receiving a discount. Therefore, the risk of material supply increases.

Due to the high risk in supplying materials and selection of and cooperation with suppliers, supply risk and suppliers were examined in the model and selected and optimized as a target function. Table 12 shows the discounts received from suppliers in the optimal solution.

As can be seen in Table 12, the benefit of suppliers discount is more colorful in the first scenario, and for \( b_3 \rightarrow M \) part, more discounts have been received from the two related suppliers, which is due to the greater capacity of the supplier. Risk assessment is one of the pillars of risk management, and its purpose is to measure risks based on various indicators, including impacts and probabilities. The more accurate the results at this stage, the more effective it is in risk management.
In the last decade, supply chain management has moved out of the intangible and has become a strategic element that can have a positive and tangible impact on the activities of organizations. The technology changes in market conditions, transformation of business practices, new expectations of partners in the supply chain, and finally the demand fluctuations are among the factors changing the supply chain.

On the other hand, identifying and managing risks within the supply chain and using coordinated approaches among the supply chain members to reduce the vulnerability of the entire supply chain are defined as supply chain risk management. The purpose of risk management is to identify high-risk situations and develop a strategy to reduce the likelihood of the occurrence and impact of high-risk events.

Accordingly and considering the importance of risk management and control in the supply chain, in this study, a multiobjective mathematical model was presented to design the supply chain network taking into account the risk in production and supply. The objectives of this mathematical model include reducing supply chain costs, adverse environmental impacts, customers’ dissatisfaction, and overall supply chain risk. Several different scenarios are defined to formulate different kinds of risks, and for each, a specific probability of occurrence is determined. A two-step stochastic programming method was applied to deal with the uncertainty of scenarios and solve the mathematical model. The results of solving this mathematical model show that by analyzing different scenarios, its impact on fixed and variable costs as well as the amount of production and supply risks in different periods can be evaluated.

After conducting this research, it can be claimed that the approach implemented can help medical product supply chain managers to manage the production and distribution process with the least possible risk. However, this research has some limitations, the most important of which are the high complexity of the mathematical model and the restriction of GAMS software in solving the model in very large dimensions.

In order to develop this research, it is suggested that new metaheuristic algorithms such as the Moth-Flame Optimization, Gray Wolf Optimization, Slap Swarm Optimization, and Sparrow Optimization be used to solve the proposed mathematical model. Uncertainty can also be considered intermittently, and a robust optimization method can be used to deal with uncertainty.

## Data Availability

No data were used to support this study.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.
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