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Research Article

Presenting a Fuzzy Multiobjective Mathematical Model of the Reverse Logistics Supply Chain Network in the Automotive Industry to Reduce Time and Energy

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The current research aims to design a fuzzy multiobjective model of the reverse logistics supply chain network in the automotive industry, taking into account the energy and time reduction approach. The automobile industry is one of the industries with a high demand worldwide. To continue the competition, the manufacturers of the leading car equipment should strive for better product quality by continuously improving their production processes, directing the production of greenhouse gases with low carbon levels, and increasing sustainability. In this regard, reverse supply chain networks and closed-loop chains have unique features that are very useful in the industry under review. The goal is to transform this model into a supply chain of a secure link in the automotive industry. Deterministic methods, genetic algorithm, particle swarm algorithm, and several scenarios with different aspects have been used to solve the model. The results show that the effectiveness of the three ways in terms of solution time is higher in the deterministic solution method. Proper use of the proposed process can help managers effectively manage the flow of recycled products concerning environmental considerations, and this process provides a sustainable competitive advantage for companies.

1. Introduction

The automobile industry is one of the industries with a high demand worldwide. This industry has long followed Henry Ford's approach based on economization, standardization, and product innovation and has progressed significantly. Today, cars are primarily mass-produced and have partial or even general renewals and the introduction of new models every few years on an annual or semiannual basis. Simple electronic devices in cars have given way to ubiquitous systems to improve the comfort, control, and safety of vehicles, all of which require careful integration into the manufactured car. All of these challenges does exacerbate by product customization to meet the unique needs of customers [1]. The primary motivating factor for companies to provide a new product or service is to pay attention to the different dimensions of the customer's demands and needs. Today, most car manufacturers have felt the need to have an optimal new product development process and have made many efforts and incurred considerable costs to have such a successful process [2].

The closed-loop supply chain involves the design, control, and implementation of a system to calculate the value during the life of a product by generating a dynamic value from different return products over time[3]. Conventional supply chain design practices look only in the direction of the forwarding flow. However, to benefit from return products, companies, in addition to direct logistics, also create reverse logistics, which cause the formation of a closed-loop supply chain [4, 5].

Meanwhile, the current situation of the automobile industry in the world shows that long-term contracts have increased, and the number of component manufacturers is decreasing. Also, competition has increased based on quality, engineering capabilities, and timely cut delivery. Therefore, parts and car manufacturers can create highly competitive supply chains through close cooperation and interaction [4, 6]. Therefore, one of the most critical research gaps in the country can be considered the interaction between the components of the supply chain and the discussion of competitiveness in the country's automotive industry. The automotive industry in Iran has had many ups and downs in the recent years. The year 1364 began with a decrease in foreign exchange earnings, signs of industrial, economic, and production crisis in the country's automobile industry, until in 1365, this industry, especially the Iran Khodro factory, was on the verge of closure. In the summer of 1991, due to the increase in the dollar rate and the tightening of sanctions, the production of cars by the Iran Khodro Company reached half compared to the previous year [6, 7]. In Table 1, the research model, target functions, established facilities, single or multiproduct, multiperiod, capacity limitation, and deficiency limitation of some past research studies are given.

Jabbarzadah et al. in an article entitled "Designing a closed-loop supply chain network under the distribution risks of a strong approach with a real-world application" state that the supply chain has become more vulnerable in today's global conditions and very unfavorable business conditions. In this paper, a simple stochastic optimization model is presented to design a closed-loop supply chain network that operates flexibly in the face of disturbances. In the proposed model, horizontal transportation was used as a reactive strategy to deal with operational and distribution risks. The goal is to minimize the facility location decisions and transportation side values, which constitute the total supply chain costs, across different distribution scenarios. The Lagrangian release algorithm is designed to solve the model effectively. Important managerial insights are derived from the implementation of the model in a case study of the glass industry. A horizontal shipping strategy can significantly reduce the cost of the entire supply chain. In addition, significant cost savings can be achieved by planning for distribution in the design of supply chain networks [4].

Considering the economic structure of Iran and the strategic position of the government in it, there are many problems in the country's automotive industry. These problems include the imposition of unilateral sanctions on the country, the occurrence of excess demand in the automotive market, the existence of multilateral monopolies among manufacturers, problems in the car pricing process, the lack of study and familiarity of consumers with customer rights, and a large number of small- and medium-sized manufacturing companies. It is parts. Planning to improve the technological capabilities of manufacturers in line with global developments [11] and more importantly, the inability of automotive manufacturers to supply the details they need, has necessitated the need to study the automotive industry. One of the innovations that today's manufacturers deal with, and at the same time, it can solve some of the problems of car manufacturers in supplying their parts, is the topic of proper disposal of vehicles and their recycling, which is in line with the resistance economy and self-sufficiency. It is primarily a car manufacturer. This research is an attempt made to present a model in this regard while reviewing the studies that are conducted in this regard at the world level. Now, the central question of this research is whether it is possible to take energy and time efficiency into account by designing a model of the reverse logistics supply chain network in the automobile industry. Also, the model considered in this research is a type of NP-hard problem, taking into account cost minimization (facility establishment costs and transportation costs), energy minimization along the way, and also considering the uncertainty in the demand for returned products, in which the time to solve the problem increases exponentially according to the dimensions of the problem. In general, the innovation aspect of this research can be seen in providing a multiobjective model according to the approach of optimizing cost and energy in the investigated industries. In this research, the researchers examine the problem from the two distinct aspects of cost and energy optimization in the automotive industry, while most researchers usually examine profit maximization.

2. Fundamentals and Theoretical Framework of the Research

The world is on a long-term strategy to achieve a climate-neutral economy. The Paris Agreement, adopted on December 12, 2015, sets the global consensus for international cooperation among countries to reduce carbon emissions [12]. At the same time, since the worldwide demand for transportation continues to increase, transportation is a significant contributor to greenhouse gas emissions. The automobile industry is one of the industries with a high demand worldwide. This industry has long followed Henry Ford's approach based on economization, standardization, and product innovation and has progressed significantly. Today, cars are primarily mass-produced and have partial or even general renewals and the introduction of new models every few years on an annual or semiannual basis. Simple electronic devices in cars have given way to ubiquitous systems to improve the comfort, control, and safety of vehicles, all of which require careful integration into the manufactured car. Likewise, fundamental changes in propulsion, from fossil fuels to electric (and hybrids in between), increase product complexity. These challenges do exacerbate by the need for variety and customization to meet unique customer preferences [13].

Meanwhile, electric vehicles reduce the impact of cars on the environment. Due to advanced programmability, autonomous vehicles can reduce road accidents, increase adequate road capacity, and reduce fuel costs. Some car manufacturers are developing the abovementioned technologies simultaneously in their product innovation, while some are innovating [14].

Table 1: Summary of several studies on reverse loop logistics.

Research studies	Types of logistics network	Models	Targets	Establishment of facilities	Multiproduct	Multiperiod	Capacity	Allowable shortage
Farrokh et al. [8]	Integrated	MILP[1]	Cost minimization	Factory of distribution/collection centers, recovery centers, and disposal centers	✓		✓	✓
Bashiri and Shiri [9]	Integrated	[2]SMILP	Cost minimization profit maximization	Collection centers factory	✓		✓	
	Reverse	MILP	Profit maximization	Reconstruction centers and inspection centers	✓	✓	✓	
Amin and Baki [2]	Integrated	MILP	Cost minimization	Production centers, collection centers	✓		✓	
Ashfari et al. [7]	Integrated	SMILP	Cost minimization maximizing customer satisfaction	Production/recovery centers and regional warehouse inspection/collection centers	✓	✓		✓
Zhou and Zhou [10]	Reverse	MINLP	Cost minimization	Recycling stations, recycling factories			✓	

[1] Mixed-integer linear programming. [2] Stochastic mixed integer linear programming.

One of the innovations that today's recyclers deal with is the proper disposal of vehicles and recycling. In this context, it is essential to emphasize the rapid increase in the demand for all kinds of auto parts and, as a result, vital materials such as cobalt, lithium, and nickel. For this reason, the significant challenges that drive automotive companies to increase the recycling of vehicle parts and equipment are the unavailability of raw materials, unbalanced supply, and demand, potential price increases, environmental impacts, human rights violations, and also raised political conflicts [14]. Therefore, these issues have increased the need to recycle and dispose of vehicles globally. The car is mainly composed of metal parts; unfortunately, the rest of the vehicle's recycling is transferred to the environment indefinitely. Thus, car recycling management becomes critical due to economic factors and environmental effects [11].

On the other hand, recent research has shown that remanufacturing has become more common in many industries due to its economic and environmental benefits. In addition, to protect the environment, many countries and regions have put forward requirements for product recycling, which turns production and consumption into a closed loop. However, forward and reverse supply chain design and interaction have challenges: in addition to meeting government recycling requirements, a closed-loop supply chain needs coordination to meet consumer's demand while meeting profit goals and achieving it [13]; as a result of the speed of technological development and economic growth, the rate of product substitution increases, which leads to an exponential increase in waste production. In reducing pollution and promoting resource reuse, collecting and reusing waste products are crucial, for which reverse logistics is essential [15]. A sustainable supply chain with proper and correct design causes minor damage to the environment. Reverse logistics in closed-loop supply chains by collecting and reusing used products in the forward direction are the best solutions for products with a limited life [16].

Therefore, reverse logistics is an environmentally friendly policy that helps protect the environment by reducing waste and pollution. In total, there are four different strategies for recovering used products. These four strategies are repair, renovation, reproduction, and recycling. Remanufacturing serves as the most crucial strategy to maintain the added value of products by giving a new life to used products. Also, remanufactured products can sell as products similar to a new development in the same or separate markets [17]. In general, reverse logistics starts with end users (first customers) where used products are collected from customers (returned products) and then attempts to dispose of end-of-life products through the decision various processes, including recycling (for raw materials or raw parts), refurbishing (for resale to secondary markets or, if possible, to primary customers), and repair (for sale in secondary markets through repair). Finally, some regular functional parts are used [18]. Now, according to the contents stated above, in this research, we are looking for the design of a fuzzy multiobjective model of the reverse logistics supply chain network in the automotive industry, considering energy and time efficiency plans.

3. Research Methodology

Figure 1 shows the closed-loop supply chain in the automotive industry [19].

The network does construct as a typical three-layer forward supply chain, namely, (1) supplier, (2) manufacturer, and (3) distributors and customers (wholesale and retail). Similarly, a three-tier structure does consider the reverse chain, including (1) vehicle delivery centers, (2) recovery centers, and (3) disposal and recycling centers. Usually, the reverse supply chain process starts with the customer going to the used car drop-off centers. The first reverse loop chain collects products from customers at delivery centers. After the initial examination, the repairable devices transfer to the recovery centers' repair facilities and the defective ones transfer to the disposal centers. In the recovery centers, suitable decisions are made based on the recycled product's type and quality and recycled items are classified. The recycled products are transferred to three locations: production facilities, disposal centers, and suppliers, based on the recovery decision. Some of the products at this stage transfer to the destruction department due to their nonrecyclability.

On the other hand, since some recycled products cannot be included in the production chain again by the manufacturer, completely healthy components are given to the suppliers. The final part of the repair and renewal operation in the reverse loop logistics cycle is assembling parts with new products (equal to the standards of new products). After quality control checks and packaging processes, these recovered products meet the demand of distribution centers and can sell to the customers at a discounted price. In the following, we will examine the research assumptions and present the mathematical functions of the investigation.

3.1. Hypothesis. In the first level of this chain, the raw materials necessary for factory production are provided by collection centers using recycled components. If recycling centers provide parts, factories can get the goods from foreign suppliers. The forward network consists of suppliers who supply various new features such as ferrous metal, rubber, primary parts, and batteries to manufacturers/distributors, where they transform into finished products (new vehicles). New cars are then distributed to user clusters. The reverse logistics network of return vehicles starts by receiving vehicles from user clusters at collection centers. Owners must return their vehicle to one of the collection or recovery centers. The next step is to transport the cars back to places of destruction or recovery. Used vehicles can be transported directly to unloading centers and pass through collection centers, recovery centers, liquids drain, and parts disassemble. Fuel, engine oil, transmission oil, hydraulic oil, coolant, air conditioning fluid, brake fluid, and steering fluid can be drained from end-of-life vehicles. While some

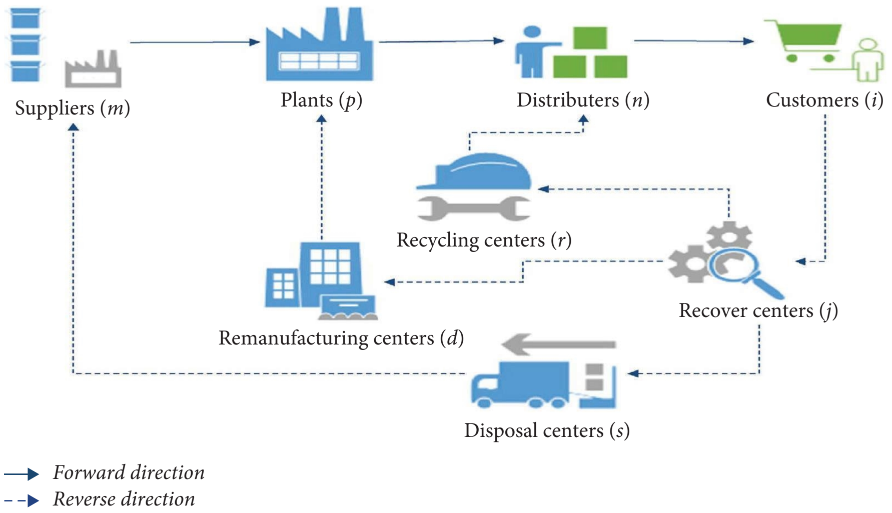

Figure 1: Closed-loop supply chain in the automotive industry.

components are sent to recyclers, the remaining is sent to shredders. In addition, reusable parts such as engines, differentials, transmissions, body panels (for example, hoods, doors, and bumpers) and wheels are resold to user clusters after restoration. After crushing, ferrous and nonferrous metals (aluminum, copper, zinc, and lead) are obtained. These materials are also sent for recycling. The sets, parameters, and variables of the model are listed in Tables 2–4, respectively.

The first objective of this research is to minimize costs. In the following, we will examine each of the expenses. The construction cost defines as an objective function, which is equal to the following:

$$\text{Construction} = \sum_{u\in U}\sum_{d\in D} f_d^u V_d^u + \sum_{u\in U}\sum_{j\in J} f_j^u V_j^u + \sum_{u\in U}\sum_{r\in R} f_r^u V_r^u + \sum_{u\in U}\sum_{n\in N} f_n^u V_n^u. \tag{1}$$

The cost of transportation of products during the reverse loop chain was defined as a function, which is as follows:

$$\begin{aligned}\text{Transportation} = {} & \sum_{t\in T}\sum_{u\in U}\sum_{s\in S}\sum_{p\in P} x_{sp}^u \text{di}_{sp} \text{C}_{spt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{p\in P}\sum_{p'\in \text{P}'} x_{pp'}^u \,\text{di}_{pp'} \text{C}_{pp't}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{p'\in \text{P}'}\sum_{d\in D} x_{p'd}^u \text{di}_{p'd} \text{C}_{p'dt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} x_{dw}^u \text{di}_{dw} \text{C}_{dwt}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{w\in W}\sum_{j\in J} x_{wj}^u \text{di}_{wj} \text{C}_{wjt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{j\in J}\sum_{r\in R} x_{jr}^u \text{di}_{jr} \text{C}_{jrt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{n\in N} x_{rn}^u \text{di}_{rn} \text{C}_{rnt}^u \\ & + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} x_{rp}^u \text{di}_{rp} \text{C}_{rpt}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{s\in S} x_{rs}^u \text{di}_{rs} \text{C}_{rst}^u + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{d\in D} x_{rd}^u \text{di}_{rd} \text{C}_{rdt}^u.\end{aligned} \tag{2}$$

Then, the assembly cost function of the parts returned to the system was investigated.

$$\text{Assembly} = \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} \text{Q}_{rp}^u cr_{rpt}^u. \tag{3}$$

The function of the disposal cost of recycled parts was defined as that these parts can be imported to the destruction center from the recovery centers and used car delivery centers.

$$\text{Annihilation} = \sum_{w\in W}\sum_{u\in U}\sum_{t\in T} W_{p't}^u H_{p't}^u + \sum_{d\in D}\sum_{u\in U}\sum_{t\in T} W_{dt}^u \text{DH}_{dt}^u. \tag{4}$$

Furthermore, finally, the function of the penalty is the cost of delay of the product to the customer in the logistics chain. This function is defined as follows:

$$\text{Penalty} = \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} \text{Cd}_{dwt}^u D_{dw}^u. \tag{5}$$

Table 2: Introduction of sets and indices.

Symbols	Definitions
S	Set of fixed points for supplier centers $s \in S$
P	Set of fixed points for centers of producers $p \in P$
P'	Set of fixed points to create warehouse centers $p' \in P'$
W	Possible number of customers (retailers) $w \in W$
D	The set of potential points for distribution centers $d \in D$
J	The set of potential points to create collection centers $j \in J$
R	The set of potential points to create general recovery centers $r \in R$
N	The set of potential points to create $n \in N$ erasure centers
T	Period (t)
U	Number of products (u)

Table 3: Model parameters.

Symbols	Definitions
C^u_{sp}	The cost of transporting the product "u" from the suppliers to the centers of producers p
$C^u_{pp'}$	The cost of transporting the product "u" from the centers of producers p to the warehouse p'
$C^u_{p'd}$	The cost of transporting the product "u" from the warehouse p' to the distributor d
C^u_{dw}	Cost of shipping the product "u" from distributors d to customer w
C^u_{wj}	The cost of transporting the recycled product "u" from the customer w to the used car collection center j
C^u_{jr}	The cost of transporting the recycled product "u" from the used car collection center j to the recycling center r
C^u_{rn}	The cost of transporting the recycled product "u" from the recycling center r to the disposal center n
C^u_{rp}	The cost of transporting the recycled product "u" from the recycling center r to the production center p
di_{sp}	The distance from the suppliers to the centers of producers p
$di_{pp'}$	Distance from producer p to warehouse p'
$di_{p'd}$	Distance from the warehouse p' to distributors d
di_{dw}	Distance from distributors d to customer w
di_{wj}	Distance from customer w to the used car collection center j
di_{jr}	Distance from used the car collection center j to recycling centers r
di_{rn}	Distance from the recycling center r to disposal center n
di_{rp}	The distance from the recycling center r to the production center p
cr^u_{rpt}	The cost of assembling the returned product from the recycling center r to production center p in period t
$\mathscr{R}^u_{rnt}$	The return rate of the product u from the recycling center r to destruction center at location n in period t
$\mathscr{R}^u_{rst}$	The return rate of the product u from the recycling center r to suppliers s in period t
$\mathscr{R}^u_{rdt}$	The return rate of the product u from the recycling center r to distributor d
$\mathscr{R}^u_{rpt}$	The return rate of the product u from the recycling center r to manufacturers p
An_n	The capacity of the disposal center in product disposal
pc^u_s	Distributors' shipping capacity s
pc^u_p	Product production capacity u in the production center p
f^u_d	The fixed cost of building a distribution center on site d
f^u_j	The cost of building a collection and recovery center in the place j
f^u_r	The cost of building a recycling center on site r
f^u_n	The cost of building a burial and destruction center in the place of n
$H^u_{p't}$	The cost of keeping the product "u" per unit in the warehouse p' in the period "t"
DH^u_{dt}	Cost of holding the product "u" per unit at distributor "d" in the period "t"
Cd^u_{dwt}	The cost of late delivery of the car from distributor d to the customer w at time t
ϑ^u_w	The amount of demand for the product u by the customer w
$\mathscr{R}^u_w$	The return rate of the product u from the customer w

Table 4: Research variables.

Symbols	Definitions
x^u_{sp}	The amount of product flow u from the suppliers to the centers of producers p
$x^u_{pp'}$	The amount of product flow u from the centers of producers p to the warehouse p'
$x^u_{p'd}$	The amount of product flow u from the warehouse p' to the distributor d
x^u_{dw}	The amount of product flow u from distributors d to the customer w
x^u_{wj}	The amount of product flow u from the customer w to the used car collection center j
x^u_{jr}	The amount of product flow u from the used car collection center j to the recycling centers r
x^u_{rn}	The amount of product flow u from the recovery center r to the elimination center n
x^u_{rp}	The amount of product flow u from the recovery center r to the producer p
x^u_{rs}	The amount of product flow u from the recovery center r to the supplier s
V^u_d	=1 if the distribution center is at location d; otherwise, = 0
V^u_j	=1 if the center of the distribution is at location j; otherwise, = 0
V^u_r	=1 if the center of the distribution is at location r; otherwise, = 0
V^u_n	=1 if the center of the distribution is at location n; otherwise, = 0
$W^u_{p't}$	The inventory amount of product u in the warehouse p' at time t
W^u_{dt}	Inventory amount of product u at distributor d at time t
D^u_{dw}	The amount of product u from the distributor d that has not been delivered to the customer w
Q^u_{rp}	The amount of recycled product u from the recycling center r to the producer p

In general, the primary objective function whose purpose is to minimize costs is generally defined as follows:

$$\begin{aligned}
\min Z = {} & \sum_{u\in U}\sum_{d\in D} f^u_d V^u_d + \sum_{u\in U}\sum_{j\in J} f^u_j V^u_j + \sum_{u\in U}\sum_{r\in R} f^u_r V^u_r + \sum_{u\in U}\sum_{n\in N} f^u_n V^u_n \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{s\in S}\sum_{p\in P} x^u_{sp} di_{sp} C^u_{spt} + \sum_{t\in T}\sum_{u\in U}\sum_{p\in P}\sum_{p'\in P'} x^u_{pp'} di_{pp'} C^u_{pp't} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{p'\in P'}\sum_{d\in D} x^u_{p'd} di_{p'd} C^u_{p'dt} + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} x^u_{dw} di_{dw} C^u_{dwt} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{w\in W}\sum_{j\in J} x^u_{wj} di_{wj} C^u_{wjt} + \sum_{t\in T}\sum_{u\in U}\sum_{j\in J}\sum_{r\in R} x^u_{jr} di_{jr} C^u_{jrt} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{n\in N} x^u_{rn} di_{rn} C^u_{rnt} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} x^u_{rp} di_{rp} C^u_{rpt} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{s\in S} x^u_{rs} di_{rs} C^u_{rst} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{d\in D} x^u_{rd} di_{rd} C^u_{rdt} + \sum_{t\in T}\sum_{u\in U}\sum_{r\in R}\sum_{p\in P} Q^u_{rp} cr^u_{rpt} + \sum_{w\in W}\sum_{u\in U}\sum_{t\in T} W^u_{p't} H^u_{p't} + \sum_{d\in D}\sum_{u\in U}\sum_{t\in T} W^u_{dt} DH^u_{dt} \\
& + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D}\sum_{w\in W} Cd^u_{dwt} D^u_{dw}.
\end{aligned} \tag{6}$$

In examining the secondary objective of the research, it can say that this function is obtained from the combination and development of two models [3, 20]. This model makes efforts to minimize the total energy consumption during each production cycle. The two main activities that consume the most energy in producing a new product include the primary production and the production of raw materials by the supplier. Similarly, in the return loop, the energy produced during the reproduction of the product in the production line, and the production of new components requires the most energy. Since not all returned products can be recycled and used in reproduction, the nutritional components of the parts must be identified and sent back into the cycle. For example, in the case of engine parts of recycled cars, it is usually in the range of 50–90%. In this model, it indicates the company's ability to recycle the product (50–70% capacity). Now, according to the stated content, the total energy used in manufacturing and reproduction is as follows:

$$\begin{aligned}
\text{Total Energy} &= T_{\text{man}f} + T_{\text{reman}f}, \\
\text{Total Energy} &= \left(E_{\text{sup}} + E_{\text{man}f}\right) x^u_{p'd} + \left(E_{\text{reman}f}\right) x^u_{rp} + \left(E_{\text{resup}}\right) x^u_{rs}.
\end{aligned} \tag{7}$$

Therefore, the second function is as follows:

$$\min Z = \sum_{u\in U}\sum_{p'\in P'}\sum_{d\in D}\left(\mathrm{E}_{\mathrm{sup}} + \mathrm{E}_{\mathrm{ma}nf}\right) x^{u}_{p'd} + \sum_{u\in U}\sum_{r\in R}\sum_{p\in P}\left(\mathrm{E}_{\mathscr{R}\mathrm{ma}nf}\right) x^{u}_{\mathrm{rp}} + \sum_{u\in U}\sum_{r\in R}\sum_{s\in S}\left(\mathrm{E}_{\mathrm{resup}}\right) x^{u}_{\mathrm{rs}}. \tag{8}$$

Here, it is necessary to explain that the meaning of $\mathrm{E}_{\mathrm{sup}}$, $\mathrm{E}_{\mathrm{manf}}$, and ($\mathrm{E}_{\mathrm{resup}}$, and $\mathrm{E}_{\mathscr{R}sup}$ can be equivalent to the greenhouse gases emitted for moving a component between a factory and a warehouse or distributor ($\mathrm{E}_{\mathrm{manf}}$), ($\mathrm{E}_{\mathrm{sup}}$) between suppliers and the factory and in the reverse loop between the recovery centers and the factory ($\mathrm{E}_{\mathrm{remanf}}$), and between the recovery centers and suppliers ($\mathrm{E}_{\mathrm{resup}}$). Since most greenhouse gas emissions occur in the transportation and warehousing sectors, it is essential to include greenhouse effects in the supply chain/logistics models provided to reduce or control environmental losses from these companies. The global warming impact of this system is the result of greenhouse gas emissions through moving parts between factories and warehouses and between warehouses and retailers and greenhouse gas emissions related to product storage. Suppose ($eCo_{2p'pu}$) is the average carbon dioxide emissions associated with moving a component of product u between p factory and $\hat{p}'$ warehouse and ($eHFC_{p'pu}$) is the moderate gas leakage HFC per unit of product u between plant p and warehouse $\hat{p}'$, the combined global warming impact of both emitted gases is measured using the principle of equilibrium between the emission of one component of HFC and one $\mathrm{GWP}_{\mathrm{HFC}}$ unit of carbon dioxide, where $\mathrm{GWP}_{\mathrm{HFC}}$ is the global warming potential of HFCs described earlier. Therefore, $eCo_{2p'pu}$ is the amount of carbon dioxide equivalent to greenhouse gases emitted for the movement of a component between a factory and a warehouse calculated as follows:

$$eCo_{2p'pu} = \mathrm{GWP}_{HFC}\cdot e\mathrm{HFC}_{p'pu} + e\mathrm{Co}_{2p'pu}. \tag{9}$$

It is necessary to explain that based on the conducted tests, the graph of the average changes of CO_2 emitted from the exhaust of cars in 1995 and 1996 had a decreasing trend and reached 185.9 grams per kilometer from 189.25 grams per kilometer (gr/km) in 1995. In the eCO2jkl function, the function of the distance in the emission of greenhouse gases is considered. It is necessary to explain that the annual constant of CO_2 gas emissions is evaluated based on statistics 106 and HFC 107. In the following, we will examine the limitations of the model. These restrictions include the following:

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{dw} = \vartheta^{u}_{w}\forall w \in W, \tag{10}$$

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{wj} = \mathscr{R}^{u}_{w}\forall w \in W. \tag{11}$$

The two relationships between (10) and (11) guarantee that all customer demands an answer in the direct flow and all the returned goods collected from the customer centers in the return flow.

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{wj} = \sum_{r\in R} x^{u}_{jr}\forall j \in J. \tag{12}$$

Equation (12) ensures that all returned products are sent to recycling centers after the collection center.

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{rd} = \mathscr{R}^{u}_{rd}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r \in R, \tag{13}$$

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{rp} = \mathscr{R}^{u}_{rp}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r \in R, \tag{14}$$

$$\sum_{u\in U}\sum_{s\in S} x^{u}_{rs} = \mathscr{R}^{u}_{rs}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r \in R, \tag{15}$$

$$\sum_{u\in U}\sum_{n\in N} x^{u}_{rn} = \mathscr{R}^{u}_{rn}\sum_{u\in U}\sum_{r\in R} x^{u}_{jr}\forall r \in R\,.\forall u \in U, \tag{16}$$

$$\sum_{u\in U}\sum_{p'\in P'}\left(x^{u}_{p'd} + \mathrm{Q}^{u}_{p'd}\right) = \sum_{u\in U}\sum_{w\in W} x^{u}_{dw} - \sum_{u\in U}\sum_{r\in R} x^{u}_{rd}\forall d \in D, \tag{17}$$

$$\sum_{u\in U}\sum_{s\in S} x^{u}_{sp} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rp} = \sum_{u\in U}\sum_{d\in D} x^{u}_{pd} + \sum_{u\in U}\sum_{p'\in P'} x^{u}_{pp'}\forall p \in P, \tag{18}$$

$$\sum_{u\in U} W^{u}_{p't} = \sum_{u\in U}\sum_{p'\in P'} x^{u}_{pp'} - \sum_{u\in U}\sum_{d\in D} x^{u}_{p'd}\forall p \in P, \tag{19}$$

$$\sum_{u\in U} \mathrm{W}^{u}_{dt} = \sum_{u\in U}\sum_{d\in \mathrm{PD}} x^{u}_{p'd} - \sum_{u\in U}\sum_{w\in W} x^{u}_{dw}\forall p' \in P'. \tag{20}$$

Equations (13)–(20) are related to the limits of flow balance in the nodes.

$$\sum_{u\in U}\sum_{d\in D} x^{u}_{p'd} \leq \sum_{u\in U}\sum_{p\in P} x^{u}_{pp'} \forall p' \in P'. \tag{21}$$

Equation (21) guarantees that the amount of output from the producers' warehouse is less than the sum of the inputs to the producers' warehouse and is less than or equal to the sum of the information to the producers' warehouse.

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{sp} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rs} \leq \sum_{u\in U}\left(\mathrm{cap}^{u}_{s} + \mathrm{pc}^{u}_{s}\right)\forall s \in S, \tag{22}$$

$$\sum_{u\in U}\sum_{p\in P} x^{u}_{pp'} + \sum_{u\in U}\sum_{p\in P} x^{u}_{p'd} \leq \mathrm{cap}_{p'} \forall p' \in P', \tag{23}$$

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{dw} + \sum_{u\in U}\sum_{r\in R} x^{u}_{rd} \leq \mathrm{cap}_{d} V_{d} \forall d \in D, \tag{24}$$

$$\sum_{u\in U}\sum_{w\in W} x^{u}_{wj} \leq \mathrm{cap}_{j} V_{j} \forall j \in J, \tag{25}$$

$$\sum_{t\in T}\sum_{u\in U}\sum_{p\in P} x^{u}_{rp}\mathscr{R}^{u}_{rpt} + \sum_{t\in T}\sum_{u\in U}\sum_{s\in S} x^{u}_{rs}\mathscr{R}^{u}_{rst} + \sum_{t\in T}\sum_{u\in U}\sum_{n\in N} x^{u}_{rn}\mathscr{R}^{u}_{rnt} + \sum_{t\in T}\sum_{u\in U}\sum_{d\in D} x^{u}_{rd}\mathscr{R}^{u}_{rdt} \leq \mathrm{cap}_{r} V_{r} \forall r \in R, \tag{26}$$

$$\sum_{u\in U}\sum_{r\in R} x^{u}_{rp} \leq \sum_{u\in U}\left(\mathrm{cap}_{r} + pc^{u}_{p} V_{r}\right)\forall p \in P, \tag{27}$$

$$\sum_{u\in U}\sum_{r\in R} x^{u}_{rn} \leq \mathrm{cap}_{n} + \mathrm{An}_{n} V_{n} \forall n \in N, \tag{28}$$

$$\sum_{t\in T}\sum_{u\in U} W^{u}_{p't} \leq \mathrm{cap}_{p'} \forall p' \in P', \tag{29}$$

$$\sum_{t\in T}\sum_{u\in U} W^{u}_{dt} \leq \mathrm{cap}_{d} \forall d \in D. \tag{30}$$

Equations (22)–(30) guarantee current flows only between points where a facility is built, and each facility's total flow does not exceed its capacity.

$$\sum_{u\in U} V^{u}_{d} \leq 1 \forall d \in D, \tag{31}$$

$$\sum_{u\in U} V^{u}_{j} \leq 1 \forall j \in J, \tag{32}$$

$$\sum_{u\in U} V^{u}_{r} \leq 1 \forall r \in R, \tag{33}$$

$$\sum_{u\in U} V^{U}_{n} \leq 1 \forall n \in N. \tag{34}$$

Equations (31)–(34) guarantee that at least one of the potential centers is active.

$$\mathscr{R}^{u}_{rdt} + \mathscr{R}^{u}_{rpt} + \mathscr{R}^{u}_{rst} + \mathscr{R}^{u}_{rnt} = 1 \forall u \in U. \tag{35}$$

Equation (35) guarantees that the sum of the coefficients of the returned products is equal to 1.

$$V_{d} \,.\, V_{j} \,.\, V_{r} \,.\, V_{n} \in \{0 \,.\, 1\} \forall d \in D \,. \forall j \in J \,. \forall r \in R \,. \forall n \in N, \tag{36}$$

$$x^{u}_{sp} .\, x^{u}_{pp'} . x^{u}_{p'd} . x^{u}_{dw} . x^{u}_{wj} . x^{u}_{jr} . x^{u}_{rn} . x^{u}_{rp} . x^{u}_{rs} . W^{u}_{p't} . W^{u}_{dt} \geq 0. \tag{37}$$

Relations between (36) and (37) are logical and self-evident related to the decision variables of the problem.

In this model, the amount of product demand is considered fuzzy.

Various methods were proposed to consider uncertainties, including the application of fuzzy logic. In cases where the available information is ambiguous, the fuzzy set theory and fuzzy mathematical programming can be used to deal with real-world uncertainties. Uncertainty in the supply chain has been widely studied in the last decade. Various parameters cannot be considered inevitable in the real world and during a supply chain design. It is reasonable to include these uncertainties as much as possible to achieve more realistic results. It is necessary to understand the demand pattern to understand the changes in customer orders. Perhaps an essential principle in the supply chain is to focus on the demand to respond to them appropriately. Although the prediction of the product demand by the customer is generally not accurate, the complete satisfaction of the customer's order is of great value [21]. This research presents a fuzzy mixed integer linear programming model for designing a closed-loop supply chain network. Solving this type of model must first be converted into a deterministic model using the fuzzy number ranking method. It assumes that we have all available information about the product demand in a particular period. Since it is not always possible to fully satisfy customer demand, we use fuzzy logic to maximize the customer demand. Also, the maximum allowable supply order is limited based on the demand forecast. In this model, the amount of need for product u by customer $\mathbf{w}$ is represented by ϑ_w^u in period t. In this research, also due to the uncertainty of the cost of building recycling and collection centers, these two components, i.e., the cost of building a recycling center in place r (f_r^u) and also the cost of building a collection and recovery center in place j (f_r^u) is considered fuzzy.

3.2. Data Analysis and Research Findings. In solving the problems, different approaches are used, including solving by exact (deterministic) and experimental methods. In solving some problems, depending on the problem's complexity and a number of variables, it is impossible to solve those using exact approaches. Therefore, these approaches are called indeterminate problems in which the solution is not obtained through conventional techniques. It means that the answer can guess, and its validity is confirmed. These problems include complicated nonlinear programming problems. In solving these problems, some algorithms can provide acceptable results with good validity and optimization of outputs. The algorithms are called metaheuristic algorithms [4]. Since closed-loop supply chain problems are complicated, nonlinear programming problems and metaheuristic methods are used to solve this problem. In this research, cost minimization and energy consumption optimization requirements provide contradictory goals.

In this research, we use the particle swarm optimization method for its ease of implementation and ability to provide good convergence, maintain a proper balance between exploitation and exploration, and a multiobjective genetic algorithm. Among random algorithms, the genetic algorithm has high efficiency and has many applications. In addition to being used in design issues, the genetic algorithm is effective in various subjects such as function optimization, combined optimization, machine learning, decision processing, system segmentation, neural network training, and control systems, as shown [22]. In addition, the particle swarm optimization technique was used. Particle swarm optimization is a robust stochastic optimization technique based on the movement and intelligence of groups. This optimization algorithm is an accurate and low-cost innovative search method whose mechanism is inspired by the group behavior of biological populations. In the particle swarm optimization simulation, an external secondary table (reservoir) is used to store the information of representatives (particles) so that each particle can make the most of this information later. Also, this algorithm does equip with a particular mutation parameter that provides more and better search possibilities [4]. Since the general stochastic multiobjective programming model is present, it is a mixed integer two-objective problem. Its objective functions conflict with each other from the consensus programming method, one of the well-known decision-making methods. Multicriteria are used to solve problems with conflicting objective functions. In the first model, we name the first and second objective functions Z2 and Z1, respectively, and according to the above explanation, the proposed model must solve for both of these functions. Suppose that the optimal solution obtained for these two functions are Z_2^* and Z_1^*, respectively, in this case, the objective part of the Lp-metrics problem, which is named Z_3, is formulated as follows:

$$\operatorname{Min} Z_3 = \left[\overline{\omega} \cdot \frac{Z_1 - Z_1^*}{Z_1^*} + (1 - \overline{\omega}) \cdot \frac{Z_2 - Z_2^*}{Z_2^*}\right]^P, \tag{38}$$

where the relative weight of the two-objective functions is Z1 and Z2 and shows the preference of the decision maker over the two-objective functions of the problem. Considering the objective function of Z3 and the limitations of the first extended stochastic model, a linear single-objective problem is obtained, which can be easily solved using software for solving mathematical programming problems (Mirzapour, Maleki, Ariannejad, 2011 : 135), and the p value specifies the degree of emphasis on existing deviations. Also, the metaheuristic algorithms did the program in the MATLAB R2016 software environment by a computer with an Intel® Core™ i5 CPU and 4 GB RAM. Then, to test the efficiency of the proposed algorithms, the results obtained from the deterministic method with the Gems software and the results obtained from the metaheuristic methods in small-sized examples have been compared with each other.

4. Research Findings

Ten problems with small, medium, and large dimensions are defined in Table 5.

Table 6 presents the nominal values of the parameters considered for solving the model.

This research uses three indicators of solution time, objective function value, and the gap between the accurate function values in two algorithms to compare the results of the two algorithms. The value of the objective function is the cost value obtained for the near-optimal solutions by each of the algorithms. The solution time in each algorithm is defined as the execution time of each algorithm to solve sample test problems and find the near-optimal solution. The third index to compare the two algorithms is the gap between the values of the objective function obtained by the two algorithms, which is calculated using the following formula:

$$\mathrm{dev} = \frac{\mathrm{Ans}(\mathrm{PSO}) - \mathrm{Ans}(\mathrm{GA})}{\mathrm{Ans}(\mathrm{PSO})}. \tag{39}$$

This criterion is the gap between the particle swarm algorithm's objective function value and the genetic

Table 5: Generated example problems.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	15	1	12	2
2	4	2	4	10	70	20	2	15	3
5	3	3	8	15	90	30	2	18	4
5	3	4	10	20	100	50	5	24	5
8	4	4	11	22	120	52	5	27	6
8	4	5	12	25	150	55	5	30	7

Table 6: Nominal values of model parameters.

Parameters	Values
f_d	$U[400, 7000] * 1000000$
f_j	$U[100, 2000] * 1000000$
f_r	$U[2000, 5000] * 1000000$
f_n	$[2000, 2700] * 1000000$
$H^{u}_{p't}$	$U[50, 500] * 1000$
DH^{u}_{dt}	$[100, 700] * 1000$
$\underset{\sim}{Cd}^{u}_{dwt}$	$[60, 100] * 1000$
ϑ^{u}_{w}	$U[20, 4000]$
cr^{u}_{rpt}	$U[5000, 100000]$
$\mathscr{R}^{u}_{w}$	$U[0.2, 0.7]$
$\mathscr{R}^{u}_{rnt}$	$U[0.1, 0.8]$
$\mathscr{R}^{u}_{rst}$	$U[0.01, 0.2]$
$\mathscr{R}^{u}_{rdt}$	$U[0.01, 0.5]$
$\mathscr{R}^{u}_{rpt}$	$U[20, 4000]$
An_n	$U[2000, 6000]$
pc^{u}_{s}	$U[1000, 90000]$
pc^{u}_{p}	$U[1000, 100000]$
di_{sp}	$U[10, 250]$
$di_{pp'}$	$U[2, 15]$
$di_{p'd}$	$U[10, 500]$
di_{dw}	$U[0.1, 10]$
di_{wj}	$U[50, 300]$
di_{jr}	$U[10, 100]$
di_{rn}	$U[10, 250]$
di_{rp}	$U[10, 200]$

algorithm's accurate function value. In this research, to check the model's accuracy, we solve it with the deterministic method. The results of solving practical problems are presented in Tables 7 and 8. Table 7 shows the solving problems in small and medium dimensions.

Figure 2 results show that the efficiency of the three methods in terms of solution time is higher than the deterministic solution method. Also, among metaheuristic solution methods, the pso method is better than the genetic method in terms of efficiency and solution time. Then, we will examine the quality of the answers in three ways (Figure 3).

In the following, we will examine and compare the answers of the second model in all three methods (Figure 4).

The results show that the answer quality is more appropriate in the deterministic and metaheuristic solutions, and the outputs of the pso method are more suitable than the genetic method.

4.1. Sensitivity Analysis and Parameter Setting.

The first step in applying and implementing a metaheuristic algorithm is choosing a method to display the answers. Converting a solution from the solution space to a chromosome is called encoding, and returning a chromosome to an explanation from the problem solution space is called decoding. The most important part of the genetic algorithm, which is considered its starting point, is this part. In providing the answers done by the chromosomes, the utmost care should be taken so that the chromosomes cover the possible space of the problem well. Then, we set the parameters of the research using the Taguchi method. To find the number of iterations, population size, and generally the adjustment factors of the genetic algorithm and the MOPSO algorithm, first run these algorithms for a problem with suitable dimensions under four scenarios according to Table 9 and analyze the results obtained and then the results. We use the Taguchi algorithm to adjust. In this method, we first normalize the obtained values of the objective function and then use the RPD method [21].

$$\mathrm{RPD} = \frac{|\mathrm{BestSol} - \mathrm{MethodSol}| \times 111}{|\mathrm{BestSol}|}. \tag{40}$$

The Taguchi method models the possible deviations from the target value and the loss function. To use the Taguchi method, we first calculate the number of times the algorithm does execute according to the defined factors and the number of scenarios. In this section, we use Minitab 17.1.0 software. According to the output of the software, since the test is performed for four factors in 4 different scenarios and also with the signaling method, the number of executions is equal to 32, the results of which are as follows (Table 10 and Figure 5).

According to the graph obtained from the experiments, the maximum signal-to-noise ratio for the npop parameter occurred at the fourth level (200), for the pc parameter at the third level (0.9), and for the pm parameter at the third level (0.3). Also, in the average graph, the minimum average occurred at the highest SNR levels. According to the test results, the algorithm's parameters can adjust as described. Any parameter whose value is higher in each level, that parameter is selected. In this section, there are eight scenarios for which we will examine the results (Tables 11–19):

(i) The first scenario is the effect of reducing the number of suppliers

Table 7: Solving problems with small and medium dimensions.

Problem numbers	GAMS			
	$Z1$	$Z2$	Z_{LP}	Time
1	80113284	$0.982452e^6$	0.0142	38
2	80308463	$1.021382e^6$	0.0153	59
3	80602724	$1.071815e^6$	0.0189	84
4	80681145	$1.092392e^6$	0.0204	123
5	80756941	$1.103849e^6$	0.0206	139
6	81082381	$1.109258e^6$	0.021	147
7	82183369	$1.061682e^6$	0.0192	265

Table 8: Computational results of solving the model with small and medium dimensions.

Numbers	(PSO)				Genetic algorithms				
	$Z1$	$Z2$	Z_{LP}	Time	$Z1$	$Z2$	Z_{LP}	Time	Dev%
1	80213561.6	$0.993394e^6$	0.016172	30.39	80012075.1	$0.983841e^6$	0.102114	5.41	0.08085
2	80684332.1	$1.020138e^6$	0.118273	48.58	80428613.8	$1.030593e^6$	0.151098	59.61	−0.0278
3	80695703.2	$1.074841e^6$	0.15742	14.89	80670872.4	$1.079542e^6$	0.165343	65.84	−0.005
4	80695638.9	$1.091239e^6$	0.15451	33.117	80688404.2	$1.10473e^6$	0.15064	3.124	−0.0956
5	80757659.3	$1.110258e^6$	0.33424	48.192	80826518.9	$1.119485e^6$	0839751	14.216	−0.01512
6	81082510.5	$1.113359e^6$	0.020759	27.361	82008390.7	$1.119468e^6$	0.067699	19.402	−0.02261
7	82193529.8	$1.065134e^6$	0.022115	64.480	83022644.4	$1.072373e^6$	0.028505	25.487	−0.0289

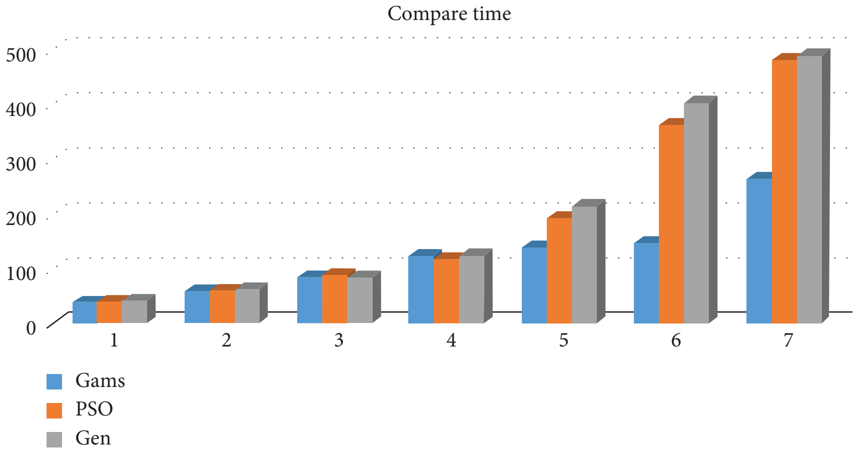

Figure 2: Comparing the efficiency of the three methods in terms of time.

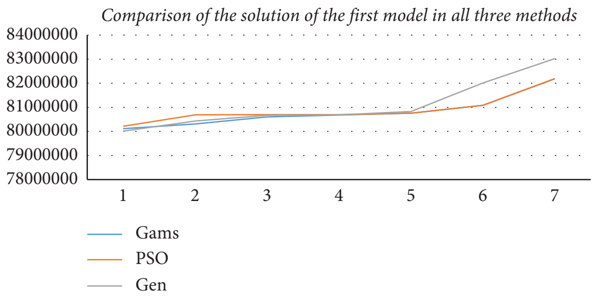

Figure 3: Comparison of the solution of the first model in all three methods.

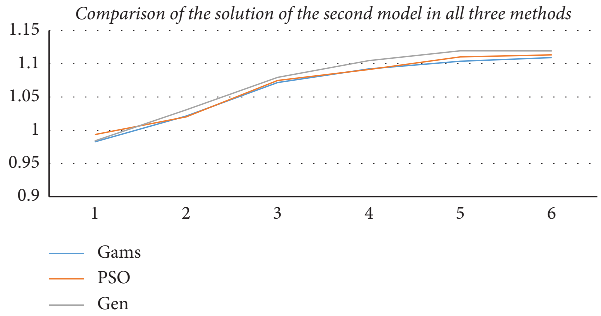

Figure 4: Comparison of the solution of the second model in all three methods.

Table 9: Search scope and the level of algorithm parameters.

Algorithms	Algorithm parameters	Parameter intervals	Down (1)	Average (2)	Average (3)	Top (4)
NSGA	nPop (A)	100–200	100	150	160	200
	Pc (B)	0.7–0.9	0.7	0.8	0.8	0.9
	Pm (C)	0.1–0.3	0.1	0.2	0.3	0.3
	nIt (D)	100–200	100	150	170	200

Table 10: Taguchi's test and the output.

Nos.	nPop (A)	Pc (B)	Pm (C)	nIt (D)	Results	
					*Z*1	*Z*2
1	100	0.7	0.1	100	80227060	98344239
2	100	0.7	0.1	100	80229536	99268691
3	100	0.8	0.2	100	80233727	98722769
4	100	0.8	0.2	150	80234949	98462359
5	100	0.8	0.3	170	80254504	99756076
6	100	0.8	0.3	170	80286119	98318166
7	100	0.9	0.3	200	80325805	98090332
8	100	0.9	0.3	200	80351272	98952117
9	150	0.7	0.2	170	80434591	98084387
10	150	0.7	0.2	170	80438102	99000841
11	150	0.8	0.1	170	80466134	98061798
12	150	0.8	0.1	200	80484707	99128316
13	150	0.8	0.3	100	80539193	99909096
14	150	0.8	0.3	100	80543857	98010037
15	150	0.9	0.3	150	80573897	98068655
16	150	0.9	0.3	150	80589294	99879789
17	160	0.7	0.3	200	80600242	98148621
18	160	0.7	0.3	200	80619278	99434486
19	160	0.8	0.3	170	80629699	98724094
20	160	0.8	0.3	170	80647873	99938537
21	160	0.8	0.1	150	80649432	99524111
22	160	0.8	0.1	150	80661124	98219896
23	160	0.9	0.2	100	80760872	99097960
24	160	0.9	0.2	100	80808109	99720353
25	200	0.7	0.3	150	80869951	99246520
26	200	0.7	0.3	150	80880755	99731871
27	200	0.8	0.3	100	80883344	98391865
28	200	0.8	0.3	100	80885121	98891820
29	200	0.8	0.2	200	80924294	99793848
30	200	0.8	0.2	200	80924898	98631582
31	200	0.9	0.1	170	80948812	99904995
32	200	0.9	0.1	150	80935738	99591277

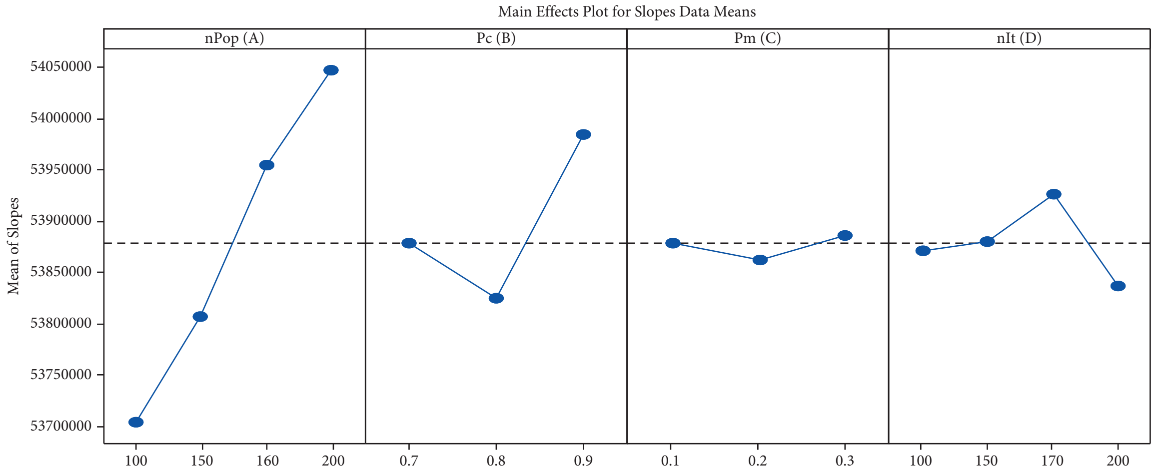

Figure 5: Taguchi output.

Table 11: First scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1–1
2	4	2	2	5	50	15	1	9	1–2
2	4	2	4	10	70	20	2	8	1–3

Table 12: Second scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	4	1	10	2
2	4	2	4	10	70	3	2	10	3

Table 13: The third scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	15	15	1	10	2
2	4	2	4	10	10	20	2	10	3

Table 14: The fourth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	2	20	5	1	10	4–1
2	4	2	2	8	50	15	1	10	4–2
2	4	2	4	12	70	20	2	10	4–3

Table 15: The fifth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	3	2	50	15	1	10	2
2	4	2	5	4	70	20	2	10	3

Table 16: Sixth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	4	2	2	5	50	15	1	10	2
2	4	4	4	10	70	20	2	10	3

Table 17: Seventh scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
1	4	1	1	1	20	5	1	10	1
2	3	2	2	5	50	15	1	10	2
2	2	2	4	10	70	20	2	10	3

Table 18: Eighth scenario.

Products	Number of courses	Elimination centers	Recovery centers	Used car delivery centers	Customer	Distributors	Production/ warehouse	Suppliers	Issue
2	4	1	1	1	20	5	1	10	1
3	3	2	2	5	50	15	1	10	2
3	2	2	4	10	70	20	2	10	3

Table 19: Output of research scenarios.

Scenarios	$Z1$	$Z2$
1–1	80113284	0/982452e^6
1–2	80105136	0/982086e^6
1–3	80098180	0/981913e^6
2–1	80113284	0/982452e^6
2–2	80990713	0/982130e^6
2–3	80913915	0/9819881e^6
3–1	80113284	0/982452e^6
3–2	79394134	0/9821356e^6
3–3	78193421	0/9821267e^6
4–1	80113284	0/982452e^6
4–2	80308463	1/021382e^6
4–3	80602724	1/071815e^6
5–1	80113284	0/982452e^6
5–2	80164922	0/982672e^6
5–3	80193001	0/9829632e^6
6–1	80113284	0/982452e^6
6–2	80146279	0/982681e^6
6–3	80157909	0/982745e^6
7–1	80113284	0/982452e^6
7–2	77437918	0/971239e^6
7–3	74579130	0/959821e^6
8–1	80113284	0/982452e^6
8–2	81713046	0/982434e^6
8–3	82933801	0/982439e^6

(ii) In the second scenario, the effect of reducing the number of distributors

(iii) In the third scenario, the effect of reducing the number of customers

(iv) In the fourth scenario, the effect of increasing the used car delivery centers

(v) In the fifth scenario, the effect of increasing recovery centers

(vi) In the sixth scenario, the effect of the increase in used car disposal centers

(vii) In the seventh scenario, the effect of reducing the number of courses

(viii) In the eighth scenario, the effect of increasing the number of product.

According to the abovementioned scenarios, the results are as follows.

5. Conclusion and Suggestions

In this research, we will examine the minimization of costs and the requirements of optimizing energy consumption, each of which can provide contradictory goals. In this research, we have used the deterministic solution method using Gems software, optimization of particle swarm due to the ability of this algorithm to provide good convergence and maintain a suitable balance between exploitation and exploration, as well as a multiobjective genetic algorithm. Remanufacturing is an industrial process that restores used products to new conditions (quality, performance, and warranty equivalent to new products) through disassembly, cleaning, inspection, repair, replacement, and reassembly. Remanufacturing is critical to realizing a resource-efficient manufacturing industry and circular economy. Through remanufacturing, which plays a good role in promoting the developed producer responsibility system, waste products' performance revives and the new value is created. Products for remanufacturing are usually auto parts and electronic equipment, large machines, etc. Reverse logistics is closely related to remanufacturing. In many reverse logistics network studies of waste products, reproduction is a necessary research content.

5.1. Managerial Insights. In reverse logistics, the network structure mainly consists of consumers, collection centers, refineries, and markets. According to the product treatment method, reverse logistics can divide into different categories: remanufacturing, recycling, disposal, etc. Some reverse logistics remanufacturing uses hybrid facilities that integrate remanufacturing centers with production centers or some are based on distribution centers' collection centers [19]. However, one of the appropriate fields for integration in the closed-loop supply chain network is the integrated design of the direct and reverse supply chain, the fast loop supply chain, which can prevent the suboptimality caused by the different configurations of the natural and reverse logistics network. Considering that one of the components of social capital is the reliability and satisfaction of customers, the stability of the production line and the receipt of used cars and their recycling are among the components that can have a positive effect on social capital. Also, the social aspect was examined as the cost and benefits received by the customer for buying a new product, as well as their results from the consequences of the problem of waste disposal of waste products. Therefore, the effects of social capital are considered indirectly in the research model. This research presents a mixed integer linear programming model for designing a closed-loop supply chain network. In fact, in this study, we have introduced a multipart optimization model to check the efficiency of the closed-loop supply chain network. The model presented in this research is considered multiproduct and multicategory, which includes transportation costs and facility construction simultaneously.

6. Results

Considering cost minimization (facility establishment costs), energy minimization along the way, and the different demands of returned products, the desired model is a type of complex nonlinear programming problem in which the time to solve the difficulty increases exponentially according to the dimensions of the problem. In general, it should state that measuring a system's environmental and economic behaviors is very difficult due to the extent and complex nature of social and ecological issues. However, environmental and economic problems certainly affect the performance measures of a supply chain system. The analysis of this research shows that the limitation of carbon dioxide emissions is positively related to the benefits of the whole system. Therefore, decision makers may consider the emission of carbon dioxide despite the existence of carbon dioxide emissions to find a way to increase profits or reduce costs. Another critical issue identified in this research is creating synergies between different flows in the closed-loop supply chain. Traditional logistics networks were like a one-way street, while the chain closed loops of multiple internal and external flows cut the liver.

In this situation, using the potential of stream integration is an essential resource for saving the scale. The integration of the direct and reverse flow reduces overhead and total costs. In general, it can say that the proper design of a suitable closed-loop supply chain, especially in Iran's automotive industry, can lead to a reduction in production costs and even a reduction in the import of products that can be produced in the country, considering the current critical economic conditions of the country. It does not have and will lead to opportunities and significant growth to create more products at a more suitable price. In future research, researchers should identify different structures of reverse logistics reproduction and its efficiency. Also, develop a model using general conditions, time value of money, inflation rate, and tax rate. Another objective function can also consider minimizing the financial risk of the manufacturing company/customer. Also, other metaheuristic methods such as neural networks can be used in closed-loop supply chain modeling.

Data Availability

Data used to support the findings of this study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] M. Alomar and Z. J. Pasek, "Linking supply chain strategy and processes to performance improvement," *Procedia CIRP*, vol. 17, pp. 628–634, 2014.

[2] S. H. Amin and F. Baki, "A facility location model for global closed-loop supply chain network design," *Applied Mathematical Modelling*, vol. 41, pp. 316–330, 2017.

[3] 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. 9, no. 3, pp. 354–373, 2022.

[4] A. Jabbarzadeh, M. Haughton, and A. Khosrojerdi, "Closed-loop supply chain network design under disruption risks: a robust approach with real-world application," *Computers & Industrial Engineering*, vol. 116, pp. 178–191, 2018.

[5] R. Lotfi, Z. Sheikhi, M. Amra, M. AliBakhshi, and G. W. Weber, "Robust optimization of risk-aware, resilient and sustainable closed-loop supply chain network design with Lagrange relaxation and fix-and-optimize," *International Journal of Logistics Research and Applications*, pp. 1–41, 2021.

[6] S. aminpour, A. irajpour, and M. yazdani, "Fuzzy multi-objective model of closed-loop supply chain network in the automotive industry with an urban management approach," *Urban Management Studies*, vol. 13, no. 47, pp. 73–90, 2021.

[7] H. Ashfari, M. Sharifi, T. Y. ElMekkawy, and Q. Peng, "Facility location decisions within integrated forward/reverse logistics under uncertainty," *Procedia CIRP*, vol. 17, pp. 606–610, 2014.

[8] M. Farrokh, A. Azar, G. Jandaghi, and E. Ahmadi, "A novel robust fuzzy stochastic programming for closed-loop supply chain network design under hybrid uncertainty," *Fuzzy Sets and Systems*, vol. 341, pp. 69–91, 2018.

[9] M. Shiri and M. Bashiri, "Multi-part collection center in a closed loop supply chain network design," in *Proceedings of the 8th International Conference on Operations Research*, Tehran, 2015.

[10] X. Zhou and Y. Zhou, "Designing a multi-echelon reverse logistics operation and network: a case study of office paper in Beijing," *Resources, Conservation and Recycling*, vol. 100, pp. 58–69, 2015.

[11] A. P. Barbosa-Póvoa, C. Silva, and A. Carvalho, "Opportunities and challenges in the sustainable supply chain: an operations research perspective," *European Journal of Operational Research*, vol. 268, no. 2, 2018.

[12] H. Fallah, H. Eskandari, S. Zgardi, and S. Chaharsooqi, "Presenting a two-level model of closed-loop supply chain network design in conditions of uncertainty and inter-chain competition: a solution with the Banders analysis approach," *Journal of Modeling in Engineering*, vol. 49, 1396.

[13] M. Fleischmann, P. Beullens, J. Bloemhof-Ruwaard, and L. Wassenhove, "The impact of product recovery on logistics network design," *Production and Operations Management*, vol. 10, no. 2, pp. 156–173, 2009.

[14] P. D. Giovanni, "A joint maximization incentive in closed-loop supply chains with competing retailers: the case of spent-battery recycling," *European Journal of Operational Research*, vol. 1, 2018.

[15] A. Haddadsisakht and S. M. Ryan, "Closed-loop supply chain network design with multiple transportation modes under stochastic demand and uncertain carbon tax," *International Journal of Production Economics*, vol. 195, pp. 118–131, 2018.

[16] Y.-W. Chen, L.-C. Wang, A. Wang, and T.-L. Chen, "A particle swarm approach for optimizing a multi-stage closed-loop supply chain for the solar cell industry," *Robotics and Computer-Integrated Manufacturing*, vol. 43, pp. 111–123, 2017.

[17] S. Hajian, A. Kazemi, M. Ali, S. Hosseini, S. Mohammad, and T. Ashlaghi, "Presenting a multi-objective model for the problem of location-routing-inventory in the multi-periodic green ring supply chain network and multi-product for perishable goods," *Industrial Management*, vol. 11, no. 1, pp. 83–110, 2019.

[18] A. M. Fathollahi-Fard, M. Hajiaghaei-Keshteli, and S. Mirjalili, "Multi-objective stochastic closed-loop supply chain network design with social considerations," *Applied Soft Computing*, vol. 71, pp. 505–525, 2018.

[19] A. S. Hassanzadeh and G. Zhang, "A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return," *Applied Mathematical Modelling*, vol. 37, 2013.

[20] H.-W. Hsiao-Fan Wang, "A closed-loop logistic model with a spanning-tree-based genetic algorithm," *Computers & Operations Research*, vol. 37, 2010.

[21] D. K. Kadambala, N. Subramanian, M. K. Tiwari, M. Abdulrahman, and C. Liu, "Closed loop supply chain networks: designs for energy and time value efficiency," *International Journal of Production Economics*, vol. 183, pp. 382–393, 2017.

[22] H. Jawad, M. Jaber, and R. Nuwayhid, "Improving supply chain sustainability using exergy analysis," *European Journal of Operational Research*, vol. 269, no. 1, pp. 258–271, 2018.