ISSN: 2783-2678

International journal of Innovation in Management Economics and Social Sciences

Journal homepage: www.ijimes.ir

Int. J. Inn. Man. Eco. Soc. Sci. Vol. 2, No 2, 61-82. (2022)

Fuzzy Robust Optimization in Closed-Loop Supply Chain Network Model for Hazardous Products (Lead-Acid Battery)

Danial Rashidi Meybodi[1], Hamed Tayebi[2], Sina Laleh[3]

[1] *Department of Industrial Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran*
[2] *Department of Industrial Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran*
[3] *Department of Industrial Engineering, Tehran West Branch, Islamic Azad University, Tehran, Iran*

ARTICLE INFO

Received: 08 February 2022

Reviewed: 28 February 2022

Revised:08 April 2022

Accept: 20 April 2022

Keywords: Closed Loop Supply Chain, Fuzzy Robust Optimization, Hazardous Products, Lead Acid Battery

ABSTRACT

Purpose: This paper models a closed-loop supply chain network problem for hazardous products in the face of demand uncertainty and variable costs. The designed model includes a set of suppliers, production centers, distribution, recycling, disposal, collection and end customers in which strategic and tactical decisions are made simultaneously. Among the decisions made in this paper is the location of production, distribution and collection centers and determining the optimal amount of product flow between the levels of the supply chain network.

Methodology: In this paper, the Epsilon constraint method is used to solve a multi-objective model in GMAS software. This article also uses uniform data to solve the problem.

Findings: The results of solving the model with fuzzy robust optimization method show that with increasing the uncertainty rate and also reducing the transfer time of hazardous products, the total network costs as well as the amount of greenhouse gas emissions have increased. Also, the study of Pareto front to optimize the total design costs and the amount of greenhouse gas emissions shows that by reducing the amount of greenhouse gas emissions in the network, the costs related to location and routing increase.

Originality/Value: In this paper a fuzzy robust optimization is used in closed-loop supply chain network model for hazardous products (Lead-Acid Battery).

[1] Corresponding Author: danirashidi@yahoo.com
https://doi.org/10.52547/ijimes.2.2.61

1. Introduction

With the growth of the industry, a large number of high-risk products have been consumed in recent decades. The most significant difference between high-risk products and conventional products is that they are harmful to the environment and human health. Overuse of hazardous products, on the other hand, results in a large amount of hazardous waste. According to the Chinese Ministry of Environment's annual environmental statistics and reports, Chinese industries produced approximately 39 million high-risk wastes in 2015 [1]. Many of the materials transported by trucks, trains, ships, and planes are flammable, explosive, toxic, corrosive, or radioactive in nature. Despite their potential for harming the environment and people, these materials are necessary for industrial development. Hazardous materials are widely used in manufacturing, mining, agriculture, and medicine, as well as in fueling vehicles and heating homes and offices. Custody transportation has increased dramatically in the last decade [2]. Specific stakeholders (e.g., environmentalists, the media) and the general public are highly sensitive to the dangers of transporting hazardous materials due to the involuntary nature and potential magnitude of these negative consequences. As a result, the government is usually in charge of regulating hazardous products transportation [3]. The importance of hazardous waste and products, as well as growing environmental concern, has necessitated the creation of a supply chain network for economically and environmentally hazardous products [4].

According to the report, hazardous waste recycling supply chain network design has become a more important strategy for businesses than it has ever been [5, 6]. More broadly, the transportation of hazardous materials is one of the most important aspects of a supply chain. Hazardous products, such as hospital waste, chemicals, flammable liquids, and other items that are transported daily between different centers, can have irreversible financial and human consequences in the event of an accident. Carrying such materials has the following negative consequences [7]:

- *Dangers of an accident in any unit of time,*
- *Dangers of spreading hazardous materials in space,*
- *Dangers of spreading hazardous substances in water,*
- *Dangers of spreading hazardous substances in the soil.*

As a result, it is critical to manage and transfer hazardous materials throughout the supply chain network. As a result, a supply chain network model for hazardous products, such as lead-acid batteries, is presented in this paper. Lead-acid batteries were the first rechargeable batteries and were discovered in 1895 by a French physicist. Lead-acid batteries are more useful because they are less expensive than newer types. The batteries that power your toys, electronics, home appliances, and automobiles are actually made up of hazardous chemicals. When a battery's acid, which is liquid, is damaged, it can leak and put you in danger. Chemical burns, respiratory problems, eye damage, and other injuries are common. Any acid used in a chemical cell or battery is referred to as battery acid. However, the term is frequently applied to the acid in a lead-acid battery, such as those found in automobiles [8, 9].

Lead acid batteries are the best choice for various applications such as cars, ships, and especially UPS because of their low price compared to other similar batteries and their high instantaneous current capability.

The re-entry of lead-acid batteries into the market and their reuse in the chemical industry has shifted the importance of the issue in the supply chain network. Lead-acid batteries are so popular that they account for nearly 80% of the world's total lead consumption [10]. The re-entry of lead-acid batteries into the market and their reuse in the chemical industry has shifted the importance of the issue in the supply chain network. Because of the importance of this topic, numerous articles in the field of closed loop supply chain network design have been published, and several authors have offered various types of models with various assumptions. As a result of the importance of designing a closed-loop supply chain network for hazardous products in this study, a supply chain network includes levels of suppliers, production centers, distribution centers, customers, collection centers, recycling and disposal centers.

2. Literature Review

The research gap in the field of supply chain network modelling for hazardous products is examined in this section. In this field, supply chain network design has piqued the interest of many researchers. To design an integrated forward and reverse grid, Ko and Evans proposed a nonlinear complex integer programming model and an innovative method based on a genetic algorithm. Given that uncertain parameters have an impact on supply chain design and management [11]. Kennan et al. proposed a closed-loop supply chain network model with the goal of minimising total supply chain costs and solved it using a genetic algorithm to reduce high-risk waste. Uncertain parameters, such as customer demand, emerge gradually over time in dynamic properties. For decision makers, supply chain network design necessitates a thorough examination. The decision maker must make the appropriate decision at the appropriate time period, such as monthly, quarterly, or annually. Over several years, many researchers have gradually moved towards the topic of dynamic supply chain network design [12].

Sasikumar et al. proposed a multi-stage closed-loop distribution supply chain network to recycle hazardous batteries [13]. For the closed-loop supply chain network design problem, Pishvaee et al. presented a robust optimization model [14]. Carle et al., for example, proposed a new modelling approach to activity-based multi-cycle supply chain network design problems and solved the model using an agent-based meta-heuristic approach [15]. Pazhani et al. proposed a two-objective mixed linear programming model for warehouse services and hybrid facilities to minimise total costs and maximise efficiency [16]. Hatefi and Jolai [17] discussed a robust and reliable model for integrating reverse forward and reverse supply chain network design based on a robust optimization approach. For the integrated supply chain network design problem and the separation line equilibrium, zceylan et al. proposed a nonlinear mixed integer programming formula [18]. For several post-disaster periods, Jabbarzadeh et al. designed a functional blood supply chain network and provided facility location and allocation decisions. According to our review of the literature, the majority of supply chain network design research focuses on closed-loop or multi-period supply chain network design issues. Quantitative research has looked at closed-loop supply chain network design and multi-cycle supply chain network design at the same time, particularly for high-risk products. Furthermore, because of the complexity and nonlinearity of the design models in the literature review, most studies have devised a variety of novel algorithms, but they cannot guarantee a universal optimization or a specific approximation [19].

Zeballos et al. considered several realistic supply chain cases for the problem of designing multi-cycle closed-loop supply chains, including those related to the operating and environmental costs of various modes of transportation, as well as production capacity, distribution, and storage constraints [20]. The environmental and social impacts of the new sustainable closed-loop location-routing model were presented by Zhalechian et al., who also developed a hybrid meta-heuristic algorithm [21]. Zhang et al. considered six different coordination strategies as nonlinear integer programmes with constraints in their inventory-location model for a closed-loop supply chain with uncertain demand [22]. For a multi-product-multi-product supply chain network design problem, Hafezalkotob et al. considered three objectives. Their proposed problem has three goals: maximise total profit, increase service level, and reduce operational incompatibility [23].

Ma and Li proposed a scenario-based random scheduling model and used two methods to solve the problem of designing a closed-loop supply chain network for high-risk single-cycle products [24]. An optimization model for designing a multi-product, multi-cycle closed-loop supply chain network was discussed by Mohammed et al. [25]. The issue of designing a closed-loop supply chain network with high-risk products was discussed by Ma et al [4]. They took into account both uncertain demand and the facility's efficiency and capacity expansion at the same time. To deal with uncertainty, Nayeri et al. used Fuzzy Robust Optimization (FRO), which included several sensitivity analyses on key parameters. Today, no one can deny the significance of supply chain network design and its impact on company performance. However, as a result of some environmental and social concerns/regulations, supply chain network design has become more complicated than ever [26]. Liu et al. investigated the optimization path of hazardous industrial waste treatment transportation in environmental protection companies, with the goal of storing hazardous waste and disposing of green waste, under the management of the green supply chain [27]. Takhar and Liyanage looked into the possibility of using digital technologies to track and manage more hazardous chemicals. Their design enables manufacturers to detect the use of chemicals and identify and manage the associated hazards automatically [28].

Mohabbati-Kalejahi and Vinel proposed a new mathematical model for the closed-loop supply chain network design problem, which includes two forward levels (production and distribution centers) and three backward levels (collection, recovery, and disposal centers), and the team's positioning was an emergency response. In this model, they set two objectives: lowering strategic, tactical, and operational costs, as well as reducing risk exposure in road networks [29]. Ke looked into the effects of potential disruptions on the performance of a hazardous materials emergency logistics system. To formulate two complex integer programming models, the basic and extended unit commitment models, he used a robust two-step optimization approach, as well as a column and constraint algorithm to accurately solve the proposed models [30]. Zarei et al. used an advanced probabilistic approach with the Bayesian network to present a risk analysis model for analysing the domino effects of hazardous material rail transport [31].

Based on a review of the literature, it can be concluded that there is no comprehensive model for hazardous products that includes all levels of the supply chain. As a result, using a fuzzy robust method to control uncertain parameters can add to the model's richness.

3. Problem Definition and Modeling

In this section, a sustainable closed-loop supply chain network for hazardous products is designed under uncertainty for hazardous products (lead-acid batteries) in accordance with Figure (1). The supply chain network examined in Figure (1) includes the levels of suppliers, production centers, distribution centers, customers, collection centers, recycling and disposal centers.

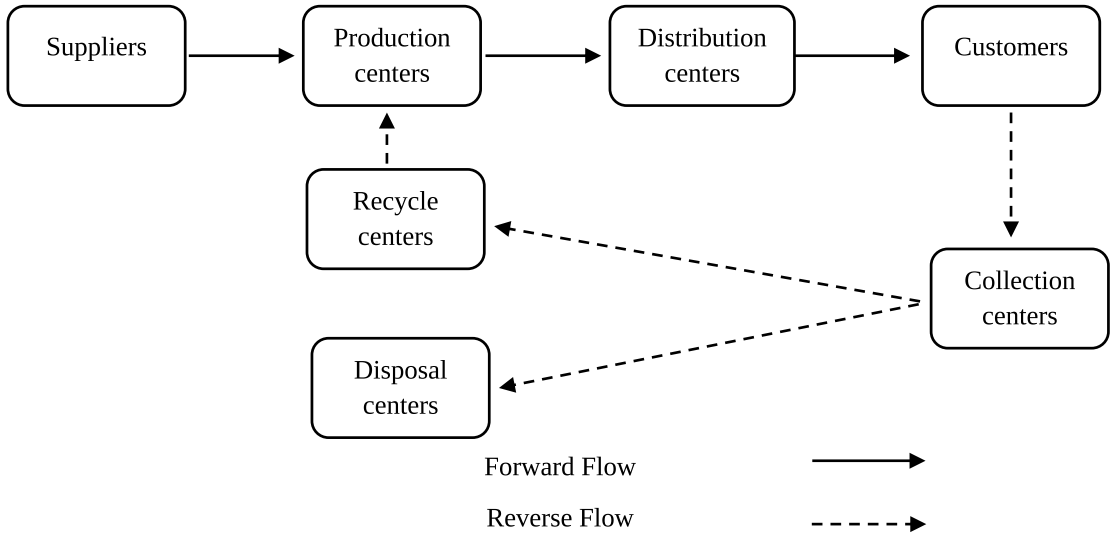

Fig. 1. Closed-loop supply chain network

Suppliers send raw materials to production centers, production centers send final products to distribution centers to meet customer demand, and distribution centers send final products to customers. Customers throw away a portion of the products after each period of use, and collection centers are responsible for collecting hazardous products. As a result, hazardous products are collected by collection centers and sent to one of the recycling centers for recycling. The recycling center sends the returned products to the production centers for reproduction if the product can be reused.

Two strategic and tactical decisions can be made in the proposed model. As a result, the number of production centers, distributors, and collection centers is determined first in the strategic decision, and then the optimal amount of product transfer by each type of vehicle in each time period is determined in the tactical decision. Furthermore, different levels of capacity exist in production, distribution, and collection centers, which should only be selected from a capacity level that is commensurate with the optimization of target functions. As a result, deciding on the facility's capacity level is one of the most crucial strategic decisions.

According to the definition of the above problem, the model of sustainable closed-loop supply chain network for hazardous products can be modeled and implemented according to the following assumptions:

- *The model under study is multi-product, multi-period.*
- *Demand parameters, transfer cost and uncertainty and fuzzy operation are considered triangular.*
- *The rate of return of products is different in each time period.*
- *Production, distribution and collection centers have different capacity levels.*
- *The product under study in this research is for lead acid batteries.*

Sets

$i = \{1, \dots, I\}$	Supplier
$j = \{1, \dots, J\}$	Production centers
$k = \{1, \dots, K\}$	Distribution centers
$l = \{1, \dots, L\}$	Customer
$c = \{1, \dots, C\}$	Collection centers
$r = \{1, \dots, R\}$	Recycling centers
$d = \{1, \dots, D\}$	Destruction centers
$p = \{1, \dots, P\}$	Hazardous products (types of acid batteries)
$t = \{1, \dots, T\}$	Period
$v = \{1, \dots, V\}$	Vehicles
$h = \{1, \dots, H\}$	Capacity level

Parameters

FJ_{jh}	Cost of selecting production center j to produce products with capacity level h
FK_{kh}	Cost of selecting distribution center k to distribute products with capacity level h
FC_{ch}	The cost of selecting a collection center c to collect products with a capacity level of h
$\widetilde{TR}_{klv}$	The cost of transporting the vehicle v between the distribution center k and the final customer l
$\widetilde{TR}_{lcv}$	The cost of transporting the vehicle v between the final customer l and the collection center c
$\widetilde{TR}_{crv}$	The cost of transporting vehicle v between the collection center c and the recycling center r
$\widetilde{TR}_{cdv}$	The cost of transporting vehicle v between the collection center c and the destruction center d
$\widetilde{TR}_{rjv}$	The cost of transporting vehicle v between the recycling center r and the manufacturer j
$\widetilde{TR}_{jkv}$	The cost of transporting vehicle v between the production center j and the distribution center k
$\widetilde{TR}_{ijv}$	The cost of transporting the vehicle v between supplier i and production center j
$Co2_{klv}$	Vehicle carbon dioxide emissions v between distribution center k and end customer l
$Co2_{lcv}$	Vehicle carbon dioxide emissions v between the final customer l and the collection center c
$Co2_{crv}$	Vehicle carbon dioxide emissions v between collection center c and recycling center r

$Co2_{cdv}$	Vehicle carbon dioxide emissions v between the collection center c and the disposal center d
$Co2_{rjv}$	Vehicle carbon dioxide emissions v between recycling center r and production center j
$Co2_{jkv}$	Vehicle carbon dioxide emissions v between production center j and distribution center k
$Co2_{ijv}$	Vehicle carbon dioxide emissions v between supplier i and production center j
$\widetilde{Cs}_{ip}$	Cost of supplying hazardous products p by supplier i
$\widetilde{Cp}_{jp}$	Cost of producing of hazardous product p by the production center j
$\widetilde{Cd}_{kp}$	Cost of distribution of hazardous product p by distribution center k
$\widetilde{Cc}_{cp}$	Cost of collecting hazardous product p by the collection center c
$\widetilde{Cr}_{rp}$	Cost of recycling hazardous product p by recycling center r
$\widetilde{Ca}_{dp}$	Cost of disposal of hazardous product p by the center of disposal center d
Cap_{jp}	Maximum production center capacity j of producing a hazardous product p
Cap_{kp}	Maximum distribution center capacity k of hazardous product p
Cap_{cp}	Maximum capacity of collection center c of hazardous product p
Cap_{ip}	Maximum supplier capacity i of hazardous product p
Cap_{rp}	Maximum capacity of recycling center r of hazardous product p
Cap_{dp}	Maximum capacity of the disposal center d of hazardous product p
$\widetilde{Dem}_{lp}$	Uncertain customer demand l of hazardous product p in period t
β_{lpt}	Percentage of hazardous return products p from end customer l in period t
γ_p	Percentage of hazardous recyclable products p
Cap_v	Maximum heterogeneous vehicle capacity v
ToT_v	Maximum time required for the transport of hazardous products from the supplier to the final customer by the vehicle v
TT_{ijv}	Transport time of hazardous products by vehicle v between supplier i and production center j
TT_{jkv}	Transport time of hazardous products by vehicle v between production center j and distribution center k
TT_{klv}	Transport time of hazardous products by vehicle v between distribution center k and end customer l

Decision variables

Z_{klpt}	The amount of hazardous product transferred p between the distribution center k and the final customer l in period t
U_{lcpt}	The amount of hazardous product transferred p between the end customer l and the collection center c in period t
O_{crpt}	The amount of hazardous product transferred p between the collection center c and the recycling center r in period t
H_{cdpt}	The amount of hazardous product transferred p between the collection center c and the disposal center d in period t
Q_{rjpt}	The amount of hazardous product transferred p between the recycling center r and production center j in period t
Y_{jkpt}	The amount of hazardous product transferred p between production center j and distribution center k in period t
X_{ijpt}	The amount of hazardous product transferred p between supplier i and production center j in period t
ZV_{klvt}	If vehicle v travels between distribution center k and end customer l in period t, it gets a value of 1 and otherwise a value of 0.
UV_{lcvt}	If vehicle v travels between the end customer l and the collection center c in period t, it gets a value of 1 and otherwise a value of 0.
OV_{crvt}	If vehicle v travels between the collection center c and the recycling center r in period t, it gets a value of 1 and otherwise a value of 0.
HV_{cdvt}	If vehicle v travels between the collection center c and the disposal center d in period t, it gets a value of 1 and otherwise a value of 0.
QV_{rjt}	If vehicle v travels between the recycling center r and the manufacturer j in period t, it gets a value of 1 and otherwise a value of 0.
YV_{jkvt}	If vehicle v travels between production center j and distribution center k in period t, it gets a value of 1 and otherwise a value of 0.
XV_{ijvt}	If vehicle v travels between supplier i and production center j in period t, it gets a value of 1 and otherwise a value of 0.
OPJ_{jh}	If production center j is selected to produce products with capacity level h, it gets a value of 1 and otherwise a value of 0.
OPK_{kh}	If distribution center k is selected to distribute products with capacity level h, it gets a value of 1 and otherwise a value of 0.
OPC_{ch}	If the collection center c is selected to collect products with capacity level h, it gets a value of 1 and otherwise a value of 0.

The controlled model of the design of a sustainable closed-loop supply chain network for hazardous products is as follows:

$$\min Z_1 = E[Z] + \xi(E[Z] - Zmin) + \\ +\eta \sum_{l=1}^{L}\sum_{p=1}^{P}\sum_{t=1}^{T}\left(Dem_{lpt}^{3} - Dem_{lpt}^{2} - \alpha\left(Dem_{lpt}^{3} - Dem_{lpt}^{2}\right)\right) \quad (1)$$

$$\min Z_2 = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{ijv}XV_{ijvt} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{jkv}YV_{jkvt} + \\ \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{klv}ZV_{klvt} + \sum_{l=1}^{L}\sum_{c=1}^{C}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{lcv}UV_{lcvt} + \\ \sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{crv}OV_{crvt} + \sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{cdv}HV_{cdvt} + \\ \sum_{r=1}^{R}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T} Co2_{rjv}QV_{rjvt} \quad (2)$$

$s.t.$:

$$\sum_{k=1}^{K} Z_{klpt} \geq (1-\alpha)Dem_{lpt}^{2} + \alpha Dem_{lpt}^{3}, \forall l,p,t \quad (3)$$

$$\beta_{lpt}\sum_{k=1}^{K} Z_{klp,t-1} = \sum_{c=1}^{C} U_{lcpt}, \forall l,p,t, \quad (4)$$

$$\gamma_p \sum_{l=1}^{L} U_{lcpt} = \sum_{r=1}^{R} O_{crpt}, \forall c,p,t \quad (5)$$

$$(1-\gamma_p)\sum_{l=1}^{L} U_{lcpt} = \sum_{d=1}^{D} H_{cdpt}, \forall c,p,t \quad (6)$$

$$\sum_{c=1}^{C} O_{crpt} = \sum_{j=1}^{J} Q_{rjpt}, \forall r,p,t \quad (7)$$

$$\sum_{j=1}^{J} Y_{jkpt} = \sum_{l=1}^{L} Z_{klpt}, \forall k,p,t \quad (8)$$

$$\sum_{i=1}^{I} X_{ijpt} + \sum_{r=1}^{R} Q_{rjpt} = \sum_{k=1}^{K} Y_{jkpt}, \forall j,p,t \quad (9)$$

$$\sum_{p=1}^{P} X_{ijpt} \leq \sum_{v=1}^{V} Cap_v XV_{ijvt}, \quad \forall i,j,t \tag{10}$$

$$\sum_{p=1}^{P} Y_{jkpt} \leq \sum_{v=1}^{V} Cap_v YV_{jkvt}, \quad \forall j,k,t \tag{11}$$

$$\sum_{p=1}^{P} Z_{klpt} \leq \sum_{v=1}^{V} Cap_v ZV_{klvt}, \quad \forall k,l,t \tag{12}$$

$$\sum_{p=1}^{P} U_{lcpt} \leq \sum_{v=1}^{V} Cap_v UV_{lcvt}, \quad \forall l,c,t \tag{13}$$

$$\sum_{p=1}^{P} H_{cdpt} \leq \sum_{v=1}^{V} Cap_v HV_{cdvt}, \quad \forall c,d,t \tag{14}$$

$$\sum_{p=1}^{P} O_{crpt} \leq \sum_{v=1}^{V} Cap_v OV_{crvt}, \quad \forall c,r,t \tag{15}$$

$$\sum_{p=1}^{P} Q_{rjpt} \leq \sum_{v=1}^{V} Cap_v QV_{rjvt}, \quad \forall r,j,t \tag{16}$$

$$TT_{ijv} XV_{ijvt} + TT_{jkv} YV_{jkvt} + TT_{klv} ZV_{klvt} \leq ToT_v, \quad \forall i,j,k,l,v,t \tag{17}$$

$$\sum_{j=1}^{J} X_{ijpt} \leq Cap_{ip}, \quad \forall i,p,t \tag{18}$$

$$\sum_{k=1}^{K} Y_{jkpt} \leq \sum_{h=1}^{H} Cap_{jhp} OPJ_{jh}, \quad \forall j,p,t \tag{19}$$

$$\sum_{l=1}^{L} Z_{klpt} \leq \sum_{h=1}^{H} Cap_{khp} OPK_{kh}, \quad \forall k,p,t \tag{20}$$

$$\sum_{l=1}^{L} U_{lcpt} \leq \sum_{h=1}^{H} Cap_{chp} OPC_{ch}, \quad \forall c,p,t \tag{21}$$

$$\sum_{c=1}^{C} O_{crpt} \leq Cap_{rp}, \quad \forall r,p,t \tag{22}$$

$$\sum_{c=1}^{C} H_{cdpt} \leq Cap_{dp}, \quad \forall d,p,t \tag{23}$$

$$\sum_{h=1}^{H} OPJ_{jh} \leq 1, \quad \forall j \tag{24}$$

$$\sum_{h=1}^{H} OPK_{kh} \leq 1, \quad \forall k \tag{25}$$

$$\sum_{h=1}^{H} OPC_{ch} \leq 1, \quad \forall c \tag{26}$$

$$\begin{aligned}
Zmin = &\sum_{j=1}^{J}\sum_{h=1}^{H} FJ_{jh}OPJ_{jh} + \sum_{k=1}^{K}\sum_{h=1}^{H} FK_{kh}OPK_{kh} + \sum_{c=1}^{C}\sum_{h=1}^{H} FC_{ch}OPC_{ch} + \\
&\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{ijv}^{1}XV_{ijvt} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{jkv}^{1}YV_{jkvt} + \\
&\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{klv}^{1}ZV_{klvt} + \sum_{l=1}^{L}\sum_{c=1}^{C}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{lcv}^{1}UV_{lcvt} + \\
&\sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{crv}^{1}OV_{crvt} + \sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{cdv}^{1}HV_{cdvt} + \\
&\sum_{r=1}^{R}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T} TR_{rjv}^{1}QV_{rjvt} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} Cs_{ip}^{1}X_{ijpt} + \\
&\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T} Cp_{jp}^{1}Y_{jkpt} + \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{p=1}^{P}\sum_{t=1}^{T} Cd_{kp}^{1}Z_{klpt} + \\
&\sum_{l=1}^{L}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{t=1}^{T} Cc_{cp}^{1}U_{lcpt} + \sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{p=1}^{P}\sum_{t=1}^{T} Cr_{rp}^{1}O_{crpt} + \sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{p=1}^{P}\sum_{t=1}^{T} Ca_{dp}^{1}H_{cdpt}
\end{aligned} \tag{27}$$

$$\begin{aligned}
E[Z] = &\sum_{j=1}^{J}\sum_{h=1}^{H} FJ_{jh}OPJ_{jh} + \sum_{k=1}^{K}\sum_{h=1}^{H} FK_{kh}OPK_{kh} + \sum_{c=1}^{C}\sum_{h=1}^{H} FC_{ch}OPC_{ch} + \\
&\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T} \left[\frac{TR_{ijv}^{1} + 2TR_{ijv}^{2} + TR_{ijv}^{3}}{4}\right] XV_{ijvt} + \\
&\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{v=1}^{V}\sum_{t=1}^{T} \left[\frac{TR_{jkv}^{1} + 2TR_{jkv}^{2} + TR_{jkv}^{3}}{4}\right] YV_{jkvt} + \\
&\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{v=1}^{V}\sum_{t=1}^{T} \left[\frac{TR_{klv}^{1} + 2TR_{klv}^{2} + TR_{klv}^{3}}{4}\right] ZV_{klvt} +
\end{aligned} \tag{28}$$

$$\sum_{l=1}^{L}\sum_{c=1}^{C}\sum_{v=1}^{V}\sum_{t=1}^{T}\left[\frac{TR_{lcv}^{1}+2TR_{lcv}^{2}+TR_{lcv}^{3}}{4}\right]UV_{lcvt}+$$

$$\sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{v=1}^{V}\sum_{t=1}^{T}\left[\frac{TR_{crv}^{1}+2TR_{crv}^{2}+TR_{crv}^{3}}{4}\right]OV_{crvt}+$$

$$\sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{v=1}^{V}\sum_{t=1}^{T}\left[\frac{TR_{cdv}^{1}+2TR_{cdv}^{2}+TR_{cdv}^{3}}{4}\right]HV_{cdvt}+$$

$$\sum_{r=1}^{R}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{t=1}^{T}\left[\frac{TR_{rjv}^{1}+2TR_{rjv}^{2}+TR_{rjv}^{3}}{4}\right]QV_{rjvt}+$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Cs_{ip}^{1}+2Cs_{ip}^{2}+Cs_{ip}^{3}}{4}\right]X_{ijpt}+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Cp_{jp}^{1}+2Cp_{jp}^{2}+Cp_{jp}^{3}}{4}\right]Y_{jkpt}+$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Cd_{kp}^{1}+2Cd_{kp}^{2}+Cd_{kp}^{3}}{4}\right]Z_{klpt}+\sum_{l=1}^{L}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Cc_{cp}^{1}+2Cc_{cp}^{2}+Cc_{cp}^{3}}{4}\right]U_{lcpt}$$

$$+\sum_{c=1}^{C}\sum_{r=1}^{R}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Cr_{rp}^{1}+2Cr_{rp}^{2}+Cr_{rp}^{3}}{4}\right]O_{crpt}+$$

$$\sum_{c=1}^{C}\sum_{d=1}^{D}\sum_{p=1}^{P}\sum_{t=1}^{T}\left[\frac{Ca_{dp}^{1}+2Ca_{dp}^{2}+Ca_{dp}^{3}}{4}\right]H_{cdpt}$$

$$Z_{klpt},U_{lcpt},O_{crpt},H_{cdpt},Q_{rjpt},Y_{jkpt},X_{ijpt}\geq 0 \quad (29)$$

$$ZV_{klvt},UV_{lcvt},OV_{crvt},HV_{cdvt},QV_{rjt},YV_{jkvt},XV_{ijvt},OPJ_{jh},OPK_{kh},OPC_{ch}\in\{0,1\} \quad (30)$$

Equation (1) shows the robust objective cost function of the network. This relationship ensures that all customer demand is met by increasing system costs. Equation (2) shows the second objective function of the problem and includes the minimization of greenhouse gas emissions due to heterogeneous vehicle traffic. Equation (3) shows the controlled demand of the model based on fuzzy robust planning relationships and ensures that customer demand is met by increasing the uncertainty rate. Equation (4) calculates the percentage of hazardous return products in the next time period he does. Equation (5) shows the percentage of recyclable products sent to the recycling center. Equation (6) calculates the percentage of non-recyclable products that should be disposed. Equation (7) shows recycled and reproducible products. Equation (8) shows the flow equilibrium relationship at the distribution center. Equation (8) shows the flow equilibrium relationship at the production center and ensures that the amount of product distribution is equal to the amount of new product produced and reproduced. Equations (9) to (15) indicate the type of vehicle suitable for the transport of hazardous products between levels of the supply chain network. Equation (16) ensures that the delivery time of hazardous products from the supplier to the customer is shorter than expected. Equations (17) to (22) show the maximum utilization of facilities by their facilities. Equations (23) to (26) ensure that each center can use a maximum of one capacity level. Equation (27) shows the most optimistic possible costs to the supply chain network. In this regard, the optimistic level of each parameter is calculated. Equation (28) shows the mathematical expectation of the costs of the total supply chain network. In this regard, according to the proof of fuzzy programming method, the weighted average of costs has been calculated. Equations (29) and (30) show the type and gender of decision variables.

Also in the above relations, the parameter ξ is the weight coefficient of the objective function and η is the cost of the penalty for not estimating the demand. The parameters α, β represent the correction coefficients in the value of the fuzzy surfaces of the numbers, which should be a number between 0.1 and 0.9.

4. Analysis of Sample Problems

This section examines a small sample problem in relation to the sizes presented in Table (1). In addition, all of the problem's parameters were generated using the uniform distribution function and based on the data in Table (2), and they were used in the model's solution. The designed model is displayed based on the size and random data input into the GAMS software, as well as the model's output.

Table 1. Size of closed-loop supply chain problem sets for hazardous products

Sets	Number	Sets	Number	Sets	Number
I	3	C	3	T	3
J	4	R	3	V	10
K	4	D	2	H	2
L	5	P	2		

Table 2. Value of closed-loop supply chain problem parameters for hazardous products

Parameter	Value
$FJ_{jh}, FK_{kh}, FC_{ch}$	$\sim U$ [10000,15000]
$Co2_{klv}, Co2_{lcv}, Co2_{crv}, Co2_{cdv}, Co2_{rjv}, Co2_{jkv}, Co2_{ijv}$	$\sim U$ [200,300]
$TR^1_{klv}, TR^1_{lcv}, TR^1_{crv}, TR^1_{cdv}, TR^1_{rjv}, TR^1_{jkv}, TR^1_{ijv}$	$\sim U$ [20,30]
$TR^2_{klv}, TR^2_{lcv}, TR^2_{crv}, TR^2_{cdv}, TR^2_{rjv}, TR^2_{jkv}, TR^2_{ijv}$	$\sim U$ [30,40]
$TR^3_{klv}, TR^3_{lcv}, TR^3_{crv}, TR^3_{cdv}, TR^3_{rjv}, TR^3_{jkv}, TR^3_{ijv}$	$\sim U$ [40,50]
$Cs^1_{ip}, Cp^1_{jp}, Cd^1_{kp}, Cc^1_{cp}, Cr^1_{rp}, Ca^1_{dp}$	$\sim U$ [4,7]
$Cs^2_{ip}, Cp^2_{jp}, Cd^2_{kp}, Cc^2_{cp}, Cr^2_{rp}, Ca^2_{dp}$	$\sim U$ [7,9]
$Cs^3_{ip}, Cp^3_{jp}, Cd^3_{kp}, Cc^3_{cp}, Cr^3_{rp}, Ca^3_{dp}$	$\sim U$ [9,12]
Cap_{jp}, Cap_{kp}	$\sim U$ [500,700]
Cap_{cp}	$\sim U$ [300,500]
Cap_{ip}	$\sim U$ [600,800]
Cap_{rp}, Cap_{dp}	$\sim U$ [200,300]
Dem^1_{lpt}	$\sim U$ [50,80]
Dem^2_{lpt}	$\sim U$ [80,100]
Dem^3_{lpt}	$\sim U$ [100,120]
β_{lpt}	$\sim U$ [0.2,0.4]
γ_p	$\sim U$ [0.1,0.4]
Cap_v	$\sim U$ [180,240]
ToT_v	500
$TT_{ijv}, TT_{jkv}, TT_{klv}$	$\sim U$ [150,200]

Due to the uncertainty modeling of the closed-loop supply chain network and the control of the model designed by the fuzzy robust optimization method, the outputs of the model analysis have been based on the following initial assumptions. Hence the value of $\xi = 2, \eta = 3$ and the value of the uncertainty rate $\alpha = 0.5$ are assumed. In the following, due to the proposed Epsilon constraint method, first, the objective functions are solved one by one by the individual optimization method. Accordingly, the optimal amount was a function of the cost of 36,163,808 monetary units (497.22 seconds) and the optimal amount was a function of greenhouse gas emissions of 12,436,917 grams of carbon dioxide (976.34 seconds). Since this research requires the simultaneous optimization of two objective functions, the Epsilon constraint method is used with the priority of the cost objective function over the objective function of greenhouse gas emissions. Therefore, after implementing the Epsilon constraint method to form different efficient solutions, Table (3) is designed.

Table 3. Set of efficient solutions of closed loop supply chain network problem by Epsilon constraint method

Efficient solutions	Cost objective function	Objective function of greenhouse gas emissions
1	36510.091	13237.284
2	36517.554	13230.531
3	36525.017	13223.779
4	36533.53	13219.352
5	36542.042	13214.925
6	36553.368	13213.578
7	36556.404	13210.996
8	36567.730	13209.649
9	36570.760	13207.068
10	37022.895	13191.831
11	37033.769	13181.911
12	37046.656	13172.678
13	37068.055	13159.019
14	37315.524	13127.419
15	37333.348	13109.711

According to Table (3), 15 different efficient solutions have been obtained from solving the closed-loop supply chain network problem for hazardous products by the Epsilon constraint method. According to the results, by limiting the amount of greenhouse gas emissions, the costs of transporting hazardous products have increased due to the criticality of the type of products and delivery in a short time. Figure (2) shows the Pareto front resulting from the solution of the closed-loop supply chain network problem for hazardous products by the Epsilon constraint method.

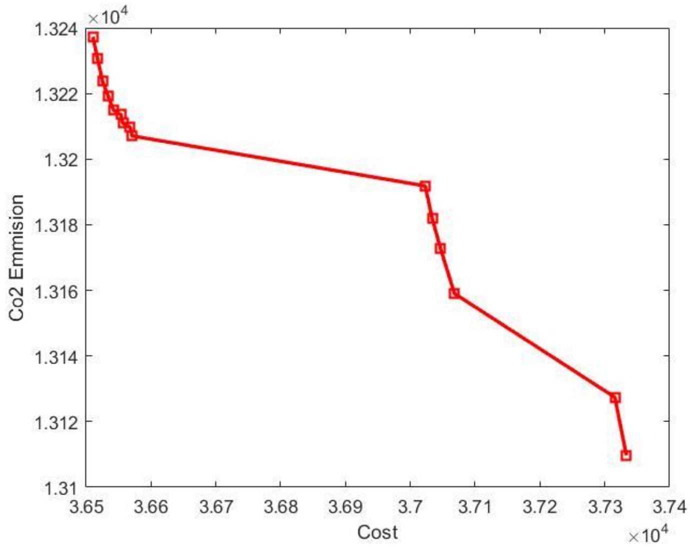

Fig. 2. Pareto front resulting from problem solving by the Epsilon constraint method

According to Figure (2), the points formed by the pareto front resulting from the solution of the closed-loop supply chain network problem for hazardous products can be seen. Accordingly, with the reduction of greenhouse gas emissions, the amount of transmission costs and consequently the costs of the total supply chain network have increased.

For a more accurate analysis of the problem, it is first shown to examine the most important variables related to the strategic decisions of the problem. Table (4) shows the number and optimal location of potential facilities of manufacturers, distributors and collection centers based on the optimization of the value of the first and second objective functions by the individual optimization method and the first efficient solution to the problem by the Epsilon constraint method.

Table 4. Number and optimal location of potential facilities in the supply chain network

Optimization method	Type of facility	Optimal center number	Center capacity level
Individual optimization of the cost function	Production center	3	2
	Distribution center	2	2
	Collection center	3	1
Individual optimization of the GHG emission function	Production center	1	1
		2	1
		3	2
		4	1
	Distribution center	1	1
		2	2
		3	1
		4	1
	Collection center	1	1
		2	1
		3	1
The first efficient solution based on the Epsilon constraint method	Production center	3	2
	Distribution center	1	1
	Collection center	1	1

According to the results of Table (4), when the purpose of the problem is to optimize the costs of the total supply chain network, the minimum facilities due to high construction costs have been used as strategic decisions of the problem. While considering the target optimization of greenhouse gas emissions, due to the lack of cost impact on this objective function, all centers have been used to shorten the distance between facilities and thus reduce pollution. On the other hand, when the goal is the simultaneous optimization of two objective functions, the cost and pollution are discussed at the same time and the type of facilities and the level of utilization of their capacity are changed. Therefore, production center No. 3 with capacity level 2, distribution center No. 1 with capacity level 1 and collection center No. 1 with capacity level 1 have been constructed.

After examining the variables related to strategic and tactical decisions, the sensitivity of the problem under change in different parameters of the problem is analyzed. Therefore, in this section, the most important analyzes resulting from changes in the objective function in exchange for changes in the values of the problem parameters are examined. Therefore, first the changes in the values of the objective functions of the problem in the efficient answer number (1) in exchange for changes in the rate of uncertainty are investigated. Table (5) shows the value of the first and second objective functions of the problem under different rates of uncertainty as well as the amount of changes in the objective functions.

Table 5. Values of the first and second objective functions at different rates of uncertainty

Uncertainty rate	The value of the objective function 1	The value of the objective function 2	Percentage of changes for the objective function 1	Percentage of changes for the objective function 2
0.1	36379.770	12536.750	-0.36	-5.29
0.2	36410.140	12731.837	-0.27	-3.82
0.3	36435.736	12789.750	-0.20	-3.38
0.4	36468.468	13002.116	-0.11	-1.78
0.5	36510.091	13237.284	0.00	0.00
0.6	36531.820	13746.281	0.06	3.85
0.7	36546.115	14149.686	0.10	6.89
0.8	36748.942	15417.654	0.65	16.47
0.9	36891.036	16397.790	1.04	23.88

According to Table (5), it can be seen that with the increase of uncertainty rate, the total demand of the supply chain network of the first and second hazardous products has increased. As the demand in the network increases, so does the supply of raw materials, production, and distribution. Accordingly, transmission costs and operating costs at each level of the supply chain network have also increased. Summarizing the above, it can be seen that with increasing uncertainty rates, the costs of the total closed-loop supply chain network have increased. On the other hand, with the increase in the amount of product transfer due to the increase in demand in the network, the amount of transportation by vehicles has also increased and as a result, the amount of greenhouse gas emissions due to the transfer of hazardous materials between facilities has also increased. On the other hand, by examining the trend of changes in the amount of cost and emissions, it is observed that the percentage of changes in the rate of uncertainty in the cost objective function was much less than changes in emissions. Figure (3) shows the amount and percentage of changes in objective functions in exchange for changes in the rate of uncertainty.

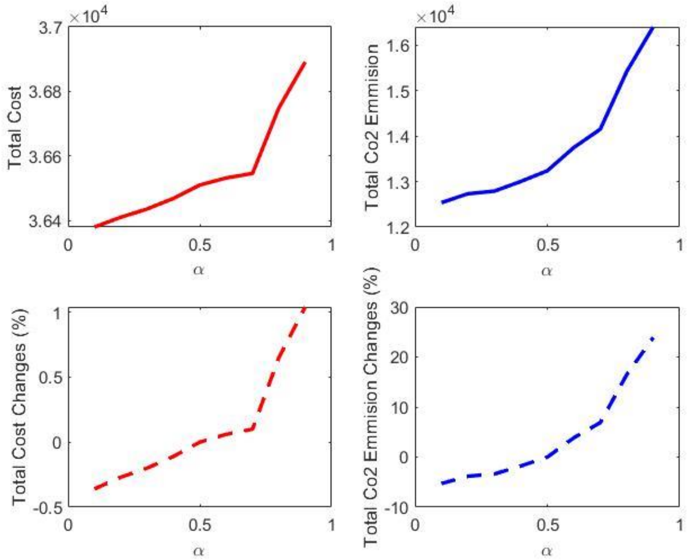

Fig. 3. The trend of changes in the objective functions of the problem in exchange for changes in the rate of uncertainty

Due to the corruption of products in the proposed closed-loop supply chain network, there is a need for rapid transfer of products within a time limit from the supplier to the end customers. Therefore, in this section, by changing the total delivery time of products to customers, changes in the amount of cost target functions as well as the amount of greenhouse gas emissions are investigated. In the initial model, the time limit value of 500 time units was considered. Table (6) shows the value of the first and second objective functions and the percentage of changes in different product transfer times.

Table 6. The values of the first and second objective functions in the maximum transfer time of hazardous products

Maximum product transfer time	The value of the objective function 1	The value of the objective function 2	Percentage of changes for the objective function 1	Percentage of changes for the objective function 2
400	42685.16	15137.49	16.91	14.35
440	40136.64	14268.80	9.93	7.79
480	37194.14	14049.64	1.87	6.14
500	36510.09	13237.28	0.00	0.00
520	36426.82	13049.94	0.20	-1.42
560	35198.10	12567.49	-3.59	-5.06
600	34283.61	12381.18	-6.10	-6.47
640	31498.16	11976.49	-13.7	-9.52

According to the results of Table (6), it is observed that with the increase of transfer time of hazardous products from the supplier to the customer, the costs of the total supply chain network and, of course, the amount of greenhouse gas emissions have decreased. This is due to the possibility of transferring products from lower cost routes. Figure (4) shows the amount and percentage of changes in target functions for changes in maximum transfer time.

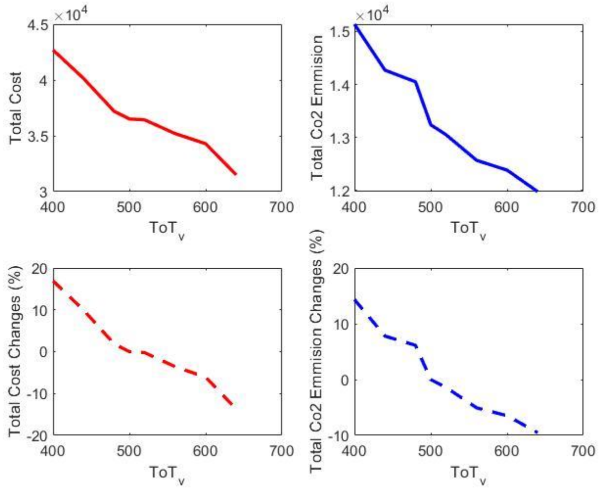

Fig. 4. The process of changing the objective functions of the problem in exchange for changes in the maximum transfer time

Finally, in the last analysis, the effect of the amount of products returned to the reproduction cycle on the objective functions of the problem is investigated. Therefore, the rate of return of the product is 10, 20 and 30% less and more than the base value in the calculations. Table (7) shows the changes and the percentage change of the value of the first and second objective functions of the problem at different rates of product return. Figure (5) also shows the trend of changes in total cost values and greenhouse gas emissions in exchange for changes of 10, 20 and 30% in the rate of crop return.

Table 7. The values of the first and second target functions at different product return rates

Product return rate	The value of the objective function 1	The value of the objective function 2	Percentage of changes for the objective function 1	Percentage of changes for the objective function 2
-30 %	37105.64	13944.56	5.34	1.63
-20 %	36946.19	13765.26	3.99	1.19
-10 %	36649.02	13552.12	2.38	0.38
0	36510.09	13237.28	0.00	0.00
+10 %	36234.67	13129.94	-0.81	-0.75
+20 %	35946.55	12946.29	-2.20	-1.54
+30 %	35567.94	12766.46	-3.56	-2.58

Based on the results of Table (7), it is observed that with decreasing product return rate, the need to produce new products and increase transportation in the supply chain network arises, which leads to increased production costs, transportation and thus increase costs. The total supply chain network is closed loop. On the other hand, with the increase of product return rate, due to more use of returned products, the amount of transportation decreases and as a result, the amount of greenhouse gas emissions decreases. Therefore, Figure (6) shows the trend of changes in the values of the first and second objective functions in exchange for changes in the rate of return of the product.

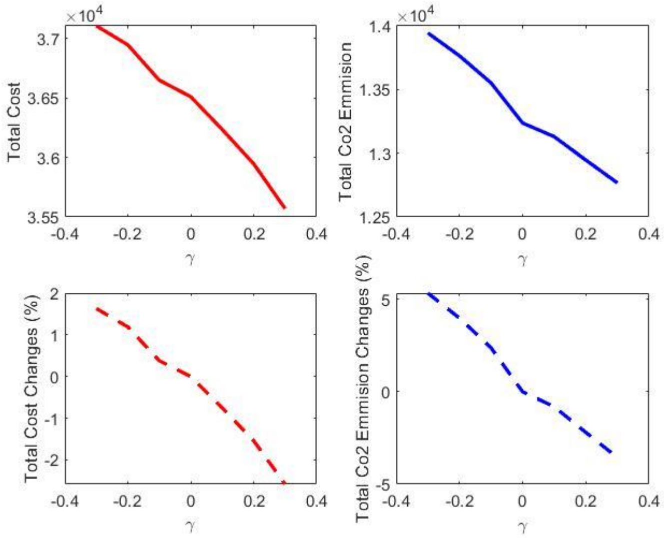

Fig. 6. The trend of changes in the objective functions of the problem in exchange for changes in the rate of return of the product

5. Conclusion

In this research, a supply chain network problem was modeled for hazardous products including lead acid batteries. Battery acid can be attributed to any acid used in a chemical cell or battery. But the term is commonly used for acid in a lead-acid battery, such as that used in motor vehicles. For example, car battery acid contains 30-50% sulfuric acid in water. Usually this compound has a molar fraction of 29-32% sulfuric acid, with a density of 1.25 - 1.28 kg per liter. The batteries you use to operate toys, electronics, home appliances, and vehicles are actually filled with hazardous chemicals. When a battery is damaged, its acid, which is liquid, can leak and put you in danger. Damages include chemical burns, respiratory problems, eye damage, and the acid used in batteries is sulfuric acid, which, like hydrochloric acid, is highly acidic and corrosive. The relatively low price of this type of battery compared to other similar batteries as well as their high instantaneous current capability make lead acid batteries the best choice for various uses such as cars, ships and especially UPS.

The model simultaneously decided on strategic variables such as the location of production, distribution and collection centers and tactical variables such as the amount of lead-acid battery transfer between facilities. Since in this network some costs such as transfer costs and operating costs as well as demand were considered as uncertain, the fuzzy robust programming method was used to control uncertain parameters. The use of this optimization method has been used to justify the problem due to drastic changes in the amount of demand. To investigate the proposed model with two objective functions of minimizing the total cost of network design and minimizing the amount of greenhouse gas emissions, a problem with known dimensions was designed and random data were used according to the uniform distribution function. As a result of the studies, it was observed that 15 efficient answers were obtained from solving the multi-objective problem. The study of the first efficient answer showed that the use of re-products is necessary to reduce the costs of the total network. It was also observed that due to the lack of cost effect in the second objective function of the problem, all potential facilities including suppliers, manufacturers, and collection centers have been constructed to reduce the distance. This is while the number of optimal facilities of each type was 1 center.

Examining the changes in the uncertainty rate, it was observed that the increase in the uncertainty rate has led to an increase in the demand for hazardous products in the network, and therefore the total network costs and greenhouse gas emissions have increased due to increased transfers. Also, by examining the changes in the maximum transfer time of hazardous products, it was observed that the reduction of this time has led to an increase in costs due to the choice of routes with higher costs and shorter time.

References

[1] Court, C. D., Munday, M., Roberts, A., & Turner, K. (2015). Can hazardous waste supply chain 'hotspots' be identified using an input–output framework?. *European Journal of Operational Research*, *241*(1), 177-187. https://doi.org/10.1016/j.ejor.2014.08.011

[2] Mohri, S. S., Mohammadi, M., Gendreau, M., Pirayesh, A., Ghasemaghaei, A., & Salehi, V. (2021). Hazardous material transportation problems: A comprehensive overview of models and solution approaches. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2021.11.045

[3] Hu, H., Du, J., Li, X., Shang, C., & Shen, Q. (2020). Risk models for hazardous material transportation subject to weight variation considerations. *IEEE Transactions on Fuzzy Systems*, *29*(8), 2271-2282. DOI: 10.1109/TFUZZ.2020.2997467

[4] Ma, H., Li, X., & Liu, Y. (2020). Multi-period multi-scenario optimal design for closed-loop supply chain network of hazardous products with consideration of facility expansion. *Soft Computing*, *24*(4), 2769-2780. https://doi.org/10.1007/s00500-019-04435-z

[5] Nozari, H., Ghahremani-Nahr, J., & Szmelter-Jarosz, A. (2022). A multi-stage stochastic inventory management model for transport companies including several different transport modes. International Journal of Management Science and Engineering Management, 1-11. https://doi.org/10.1080/17509653.2022.2042747

[6] Ghahremani Nahr, J., Kian, R., & Rezazadeh, H. (2018). A modified priority-based encoding for design of a closed-loop supply chain network using a discrete league championship algorithm. *Mathematical problems in engineering*, *2018*. https://doi.org/10.1155/2018/8163927

[7] Yang, Q., Chin, K. S., & Li, Y. L. (2018). A quality function deployment-based framework for the risk management of hazardous material transportation process. Journal of Loss Prevention in the Process Industries, 52, 81-92. https://doi.org/10.1016/j.jlp.2018.02.001

[8] Degla, A., Chikh, M., Chouder, A., Bouchafaa, F., & Taallah, A. (2018). Update battery model for photovoltaic application based on comparative analysis and parameter identification of lead–acid battery models behaviour. *IET Renewable Power Generation*, *12*(4), 484-493.

[9] Szmelter-Jarosz, A., Ghahremani-Nahr, J., & Nozari, H. (2021). A neutrosophic fuzzy optimisation model for optimal sustainable closed-loop supply chain network during COVID-19. Journal of Risk and Financial Management, 14(11), 519. https://doi.org/10.3390/jrfm14110519

[10] Subulan, K., Taşan, A. S., & Baykasoğlu, A. (2015). A fuzzy goal programming model to strategic planning problem of a lead/acid battery closed-loop supply chain. Journal of Manufacturing Systems, 37, 243-264. https://doi.org/10.1016/j.jmsy.2014.09.001

[11] Ko, H. J., & Evans, G. W. (2007). A genetic algorithm-based heuristic for the dynamic integrated forward/reverse logistics network for 3PLs. Computers & Operations Research, 34(2), 346-366. https://doi.org/10.1016/j.cor.2005.03.004

[12] Kannan, G., Sasikumar, P., & Devika, K. (2010). A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling. *Applied mathematical modelling*, *34*(3), 655-670. https://doi.org/10.1016/j.apm.2009.06.021

[13] Sasikumar, P., & Haq, A. N. (2011). Integration of closed loop distribution supply chain network and 3PRLP selection for the case of battery recycling. *International Journal of Production Research*, *49*(11), 3363-3385. https://doi.org/10.1080/00207541003794876

[14] Pishvaee, M. S., Rabbani, M., & Torabi, S. A. (2011). A robust optimization approach to closed-loop supply chain network design under uncertainty. *Applied mathematical modelling*, *35*(2), 637-649. https://doi.org/10.1016/j.apm.2010.07.013

[15] Carle, M. A., Martel, A., & Zufferey, N. (2012). The CAT metaheuristic for the solution of multi-period activity-based supply chain network design problems. *International Journal of Production Economics*, *139*(2), 664-677. https://doi.org/10.1016/j.ijpe.2012.06.016

[16] Pazhani, S., Ramkumar, N., Narendran, T. T., & Ganesh, K. (2013). A bi-objective network design model for multi-period, multi-product closed-loop supply chain. *Journal of industrial and production engineering*, *30*(4), 264-280. https://doi.org/10.1080/21681015.2013.830648

[17] Hatefi, S. M., & Jolai, F. (2014). Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions. *Applied mathematical modelling*, *38*(9-10), 2630-2647. https://doi.org/10.1016/j.apm.2013.11.002

[18] Özceylan, E., Paksoy, T., & Bektaş, T. (2014). Modeling and optimizing the integrated problem of closed-loop supply chain network design and disassembly line balancing. *Transportation research part E: logistics and transportation review*, *61*, 142-164. https://doi.org/10.1016/j.tre.2013.11.001

[19] Jabbarzadeh, A., Fahimnia, B., & Seuring, S. (2014). Dynamic supply chain network design for the supply of blood in disasters: A robust model with real world application. *Transportation Research Part E: Logistics and Transportation Review*, *70*, 225-244. https://doi.org/10.1016/j.tre.2014.06.003

[20] Zeballos, L. J., Méndez, C. A., & Barbosa-Povoa, A. P. (2016). Design and planning of closed-loop supply chains: a risk-averse multistage stochastic approach. *Industrial & Engineering Chemistry Research*, *55*(21), 6236-6249. https://doi.org/10.1021/acs.iecr.5b03647

[21] Zhalechian, M., Tavakkoli-Moghaddam, R., Zahiri, B., & Mohammadi, M. (2016). Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *89*, 182-214. https://doi.org/10.1016/j.tre.2016.02.011

[22] Zhang, Z. H., & Unnikrishnan, A. (2016). A coordinated location-inventory problem in closed-loop supply chain. *Transportation Research Part B: Methodological*, *89*, 127-148. https://doi.org/10.1016/j.trb.2016.04.006

[23] Hafezalkotob, A., Khalili-Damghani, K., & Ghashami, S. S. (2016). A three-echelon multi-objective multi-period multi-product supply chain network design problem: A goal programming approach. *Journal of Optimization in Industrial Engineering*, *10*(21), 67-78. DOI: 10.22094/joie.2016.262

[24] Ma, H., & Li, X. (2018). Closed-loop supply chain network design for hazardous products with uncertain demands and returns. Applied Soft Computing, 68, 889-899. https://doi.org/10.1016/j.asoc.2017.10.027

[25] Mohammed, F., Selim, S. Z., Hassan, A., & Syed, M. N. (2017). Multi-period planning of closed-loop supply chain with carbon policies under uncertainty. *Transportation Research Part D: Transport and Environment*, *51*, 146-172. https://doi.org/10.1016/j.trd.2016.10.033

[26] Nayeri, S., Paydar, M. M., Asadi-Gangraj, E., & Emami, S. (2020). Multi-objective fuzzy robust optimization approach to sustainable closed-loop supply chain network design. Computers & Industrial Engineering, 148, 106716. https://doi.org/10.1016/j.cie.2020.106716

[27] Liu, Z., Wu, Y., Liu, T., Wang, X., Li, W., Yin, Y., & Xiao, X. (2021). Double Path Optimization of Transport of Industrial Hazardous Waste Based on Green Supply Chain Management. Sustainability, 13(9), 5215. https://doi.org/10.3390/su13095215

[28] Takhar, S. S., & Liyanage, K. (2021). Transforming product labels using digital technologies to enable enhanced traceability and management of hazardous chemicals. International Journal of Supply Chain and Operations Resilience, 5(1), 27-59.

[29] Mohabbati-Kalejahi, N., & Vinel, A. (2021). Robust Hazardous Materials Closed-Loop Supply Chain Network Design with Emergency Response Teams Location. *Transportation Research Record*, *2675*(6), 306-329. https://doi.org/10.1177/0361198121992071

[30] Ke, G. Y. (2022). Managing reliable emergency logistics for hazardous materials: A two-stage robust optimization approach. Computers & Operations Research, 138, 105557. https://doi.org/10.1016/j.cor.2021.105557

[31] Zarei, E., Gholamizadeh, K., Khan, F., & Khakzad, N. (2022). A dynamic domino effect risk analysis model for rail transport of hazardous material. *Journal of Loss Prevention in the Process Industries*, *74*, 104666. https://doi.org/10.1016/j.jlp.2021.104666.