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Designing a model for optimizing reverse logistics based on waste management to reduce environmental impacts

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Abstract Solid waste has become one of the most critical environmental issues in the world. Therefore, a waste management system to prevent further destruction of the environment is essential. Waste management includes collection, transport, cleaning, recycling, and disposal of the wastes. In recent years, due to environmental concerns, manufacturers have been forced to offer environmentally friendly products. So, the area of reverse logistics (RL) has recently received considerable attention, due to a combination of environmental, economic, and social factors.

In this research, the design of a multi-product and eleven-level reverse logistics network is conducted, which collects all the waste in one place and separates them according to the needs of the factories (in terms of the type and material of the waste, etc.) and sends them to the intended destination. This model can support all kinds of industries in which the revival of recycling and destruction of products.

This study provides a mixed integer mathematical model to reduce the costs of the whole system. The number of centers, the number of products and parts that should be sent from one center to another, the amount of CO_2 emissions, and the total cost of the model were determined. Finally, the sensitivity analysis was done on the parameters of the model. The model was validated by changing the input data in two different cases.

Sensitivity analyses are conducted on various parameters to illustrate the capabilities of the proposed model. The results reveal that the allowed cost of CO_2 emissions has a significant effect on the value of the objective function.

Keyword: Model, Optimization, Reverse Logistic, Waste Management, Environmental Impact.

1 Introduction and literature review

Today, economic and industrial changes are occurring faster than before. Due to the trend of globalization, the minimization of the world and the increase of competition are more tangible in countries. Customers seek goods and services that can meet their requirements and on the other hand, companies attempt to maintain profit and create competitive advantages to survive in the market. All the above-mentioned factors have led to more attention to the supply chain

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and integrated logistics. Making the activities of the supply chain more efficient and effective is considered a sustainable competitive advantage for countries and companies. Logistics activities are a main part of the efficiency-making efforts which can make the costs economical and affordable. Efficient logistics activities management, in addition to being an important source of creating competitive advantages, can be followed by the satisfaction of customers and meeting their certain needs and requirements. In this regard, a new approach, namely reverse logistics has appeared regarding the issue of logistics.

Logistics includes the physical part of the supply chain and mostly, it involves all the activities related to the materials and goods flow from the stage of providing raw materials to the stage of the final production such as transportation, warehousing, etc. in logistics management, there is a new approach including recycling, recovery and reuse products. In this method, the products whose shell life has been ended are purchased again from the end user and after dismantling, the parts that can be reused are recycled in the form of wasted products.

The proposed reverse logistics models can be investigated from the three following perspectives

- Modeling for reuse
- Modeling for recycling
- Modeling for regeneration

Modeling for reuse: Kroon et al. (1995) proposed a linear MIQP model for the products that could be reused. The proposed model was a location model without the classic capacity limitation which was designed for the case study of reusable transportation boxes. [1]

Modeling for recycling: Baroos et al. (1998) presented a linear MIQP model for reverse logistics network design in a two-rank chain with a limited capacity to recycle stone. The presented model specified the number and optimal capacity of stores using an innovative approach. [2]

Modeling for regeneration: Jayaraman et al. (1998) proposed a linear MIQP model for reverse logistics network design to minimize costs. In this study, only the activities related to the recovery of the returned products were investigated, aiming at designing a pull system based on customers' needs. [3]

Jayaraman et al. (2003) presented a linear MIQP model for reverse logistics network design. Their proposed model which was constructed at strategic levels revealed which of the regeneration centers should be constructed concerning the returned products.[4]

Krikke et al. (1999) presented an MIQP model for a two-rank reverse logistics network for a copy device manufacturer. In this model, the costs of the returned products and the inventory were considered in the target function.[5]

Min et al. (2005) further presented a nonlinear MIQP to minimize the costs using the binary approach in the genetic algorithm.[6]

Kim et al. (2006) proposed an overall framework for regeneration such that the proposed mathematical model aiming at minimizing the profit obtained from the optimal use of resources decided for the number of items (pieces) to be purchased and the number of items used in each production center. [7]

One of the important factors in logistics network design is the uncertainty of demand as well as the type and quality of returned products. Considering this fact in a stone production network, Lists and Dekker (2005) attempted to present a random MIQP aiming at minimizing costs. They developed this model for several cases by considering the various scenarios.[8]

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Aras et al. (2007) proposed a nonlinear model to locate the collection center of the consumed products in a simple reverse logistics network. Notably, this study was able to determine the purchase price of the consumed products to maximize the obtained profit. To solve the model, they used an innovative method based on the Tabu Search (TS) method [9].

Uster et al. (2007) designed a semi-integrated network in which a direct logistics network was supposed available and only collection and recovery centers were located in logistics but the direct and reverse flow was optimized simultaneously. Notably, an analysis-based precise solution was designed for the model [10].

Frota Neto et al. (2008) presented a framework to design and evaluate sustainable reverse logistics networks based on data envelopment analysis (DEA) and multi-objective planning. To validate the proposed model, it was implemented in the paper and paste industry in Europe. In the suggested two-objective model, minimizing the costs and environmental impacts were considered as the two objectives in logistics network design [11].

Pati et al. (2008) presented a model based on the ideal MIP to solve and investigate the relations of objectives in a paper recycling distribution network. Decreasing the costs of reverse logistics (modeling for recycling) was one of the model's objectives [12].

According to the reports, most of the previously done research has studied only one of the main processes and operations of reverse logistics. Therefore, since the activities including regeneration, reuse, repair, and recycling are regarded as the main activities in all reverse logistics models, it seems that it is useful to present a model entailing recycling for the use of recyclable products and materials and regenerating for reusing pieces in production. Thus:

Lee et al. (2009) proposed a three-rank reverse logistics network using an IP model to minimize the costs of reverse logistics [13].

However, studying logistics and reverse design separately and non-simultaneously can cause sub-optimality. The integrated logistics network design can lead to sub-optimality and it can also be considered to achieve integrity. Fleischmann et al. (2001) proved that integrated and simultaneous logistics network design, compared with the conventional approach, can cause considerable cost savings [14].

Using the combinational facilities of warehouse/collecting by warehouse/repair is another issue that has been considered in direct and reverse logistics integration. These combinational facilities play the role of distribution centers (warehouses) in the direct flow and the role of collecting, inspecting, or organizing centers or recovery centers in the reverse flow. Considering such facilities can save costs due to the integration of the direct and reverse flows and sharing the facilities and infrastructures in addition to decreasing the complexity. Lee et al. (2009) proposed a combinational linear integer model to design and plan a production-distribution system [13]. In this problem, it was attempted to consider the strategic decisions such as opening, closing, and developing facilities, selecting suppliers, and the product flow during the supply chain simultaneously.

El Seyed et al. (2008) designed a model for direct and reverse supply chain network design in which the chain logistics costs included fixed reopening costs, shipping costs,product processing costs, and inventory maintenance costs [15].

Kanan et al. (2010) proposed a multi-product, multi-period closed-loop model for the car battery recycling industry, in which the logistics costs of the model included the costs of collection, disposal, disassembly, and processing of products. GAMS software was used on a small scale to solve the mixed-numerical linear number (MILP) linear programming model, and the result was compared with the answers obtained from the genetic algorithm [16].

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Fonseka et al. (2010) presented a multi-product, multi-product, multi-product reverse logistics network in which fixed reopening costs, transportation, and collection costs were considered as logistics costs [17].

Abdullah et al. (2011) designed a correct mixed number model for a direct multi-product supply chain, which includes fixed reopening costs, and transportation of environmental costs due to CO_2 emissions. The feature of this model is not the same area of potential location. There was also a steady increase in reopening costs as the area increased [18].

Wang et al. (2011) proposed a MIP model to reduce environmental costs. Then they solved the model with CPLEX software. They concluded that improving network capacity and reducing facility supply could reduce the environmental impact. Affects CO2 and the total cost of the network [19]. Giovanni Lopez et al. (2015) presented a model based on this model of legal, environmental, and economic criteria that aimed to maximize profits by reducing the cost of transporting and selling recyclable materials.

Lee et al. (2008) proposed a multi-purpose model for locating the distribution center, including maximizing profits and minimizing the amount of carbon emissions from transportation [13].

Lee et al. (2016) presented a MIP model for urban waste in Hong Kong and then solved the model with different scenarios. Their model specifies the optimal number of facility points and the capacity of the blast furnaces [20].

Sun et al. (2016) provided a model for urban solid waste collection centers that route between transmission stations and optimized sites. The goal was to maximize waste collection. In this model, the routing of asexual vehicles and multiple transmission stations was examined, and finally, the application of this model for the city of Dong Vietnam was examined.

Das et al. (2015) presented a model for waste management that optimizes collection and transportation centers. The goal is to minimize the costs of collecting and transporting waste [21].

In this collection, it was explained how to design a logistics network in which uncertainty in the quality of the products returned from the recovery/repair center minimizes the costs of the returned products in addition to the fuzziness of the quality and the price uncertainty.

The considered network has eight levels and the network facilities include the collecting centers, the control/inspection centers, separation centers, recovery centers, piece manufacturer centers, producer centers, customer centers, and discarding centers. In the designed model, the returned products are inspected and controlled after collection and then, they are separated into two groups separable and non-separable. The products that can be separated into pieces are sent to the separation center and changed into pieces there. The pieces are divided into the classes of recoverable and non-recoverable. The non-recoverable pieces are discarded safely and the recoverable pieces are sent to the producer centers to be regenerated. Finally, the manufactured products are sent from the producer to the customer.

Kilic et al. (2015) developed an optimized reverse logistic system for the handling of waste from electrical and electronic products [22]. Darbari et al. (2017) developed a reverse logistics network model for electronic returned products that focuses on the minimization of reverse logistics cost and the maximization of the recovery facility's performance sustainability [23]. Zarbakhshnia et al. (2019) developed a forward and reverse logistics model for home appliances that consider both the economic and environmental aspects [24].

Yu et al. (2020) proposed a novel stochastic bi-objective mixed integer linear program to reduce the population's exposure to risk and maintain a high-cost efficiency of the transportation and treatment of hazardous waste [25]. Homayouni and Pishvaee (2020)

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designed a collection and disposal network of hospital wastes under uncertain conditions, and the total cost of transportation and operations costs, and the total risk of transportation and operations were minimized [26].

To meet the needs of society, natural resources are transformed into processed products that are discarded when they reach the end of their useful lives. In other words, these resources reach the ends for which they were created, generating what is called solid waste. The growing increase in the disposal of this material in the environment is due to the disordered growth of the population and income per capita, related to the inadequate production and consumption process, leading to the deterioration of the natural environment [27] (Abu Hajar et al.,2020).

Jaunich et al. (2020) presented a holistic framework for analyzing electronic waste management systems and their supply chain network under two scenarios of re-selling and recycling based on energy cost, employee wage, and facility development costs [28].

In computing the total environmental impact, researchers (Moazzeni et al.,2022; Reddy et al.,2020) uses data from existing life-cycle analysis studies, but some key information, such as the energy requirements of the remanufacturing stage, is missing from the model, and ad hoc estimates are used instead. Li et al. (2022) developed a location-allocation model to determine the number and locations of waste disposal plants in the region of Guangzhou (China) [29]while Bautista and Pereira (2006) focused on selecting the locations of municipal waste collection points in Barcelona [30]. Kannan et al. (2010) presented the development of a genetic algorithm (GA) model for recycling spent batteries [16]. Gharibi and Abdollahzadeh (2021) developed a mixed-integer linear programming (MILP) model to maximize the profit of a reverse logistics network and presented a case of mobile phones and digital camera remanufacturing [31].

A novel bi-objective MILP model to minimize total costs and population risk for designing a medical waste management network during the outbreak of COVID-19 was formulated by Govindan et al. (2021). They applied a fuzzy goal programming approach to solve their bi-objective model [32].

To design a reverse supply chain for medical waste management, a MILP model was formulated by Kargar et al. (2020a). The purpose of their model was to minimize total costs, select the best treatment technology, and minimize total medical waste stored. They applied a fuzzy goal programming approach to solve their multi-objective model [33]. Ottoni et al. (2020) framed the best e-waste management (E-WM) option as determined by using these criteria and indicators. Electronic waste (e-waste or WEEE) is a critical category when it comes to waste management. The findings suggest an alternative to a more accurate analysis for a sustainable urban grid design, such as the Gross Domestic Product (GDP) and Municipal Human Development Index [34].

Hashemi (2021) elaborated on fuzzy mathematical programming [FUM]. A multi-objective model for a reverse logistics network is what is needed to be developed. The model's objective functions include minimizing the sum of the ratio of unmet customer demand to the total amount of their demand over time, to cover all aspects of this system's costs, such as building facilities, purchasing fuel, and causing environmental damage through the emission of polluting gases [35].

The increase in e-waste has also shifted the interest of researchers toward reducing carbon usage and emissions which could help in reducing global warming (Xiao et al., 2019)[36].[37] Emissions of carbon from transportation constitute around 25% of total carbon dioxide emissions (Nanaki and Koroneos,2016) [38]. When considering the need for reuse, recovery, and recycling operations, the social perspective must be considered as well, in terms

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of job creation. However, globally the rate of unemployment was 5% which can be decreased in the future due to a rise in the number of jobs created worldwide (Kühn, 2019). This shows that an increase in the implementation of reuse, recycling, and recovery operations will not only improve resource conservation but will also lead to an increase in job creation and a decrease in the unemployment rate, globally.

Table 1 Literature review for the reverse logistic network design

Author(s)	**Subject**	**Facilities and Case studies**
Pishvaei et al. (2010) [39]	Reverse Logistics Network Design	Single product and multi-level Refrigeration simulation algorithm
El Seyed et al. (2008) [15]	Reverse Logistics Network Design	Direct and reverse supply chain
Kanan et al. (2010) [16]	Reverse Logistics Network Design	Multi-product and multi-cycle closed-loop models for the automotive battery recycling industry Solve with genetic algorithm
Fonseka et al. (2010) [17]	Reverse Logistics Network Design	Multi-objective reverse logistics, multi-product, multi-period
Abdullah et al. (2011) [18]	Reducing the Environmental Impacts	Multi-product direct supply chain The feature of this model is not the same area of potential locations
Wang et al. (2011) [19]	Reducing the Environmental Impacts	MIP model to reduce environmental costs
Lee et al. (2015)	Reducing the Environmental Impacts	Locating the distribution center of a multi-objective model of profit maximization and minimization of carbon emissions from transportation
Lee et al. (2016) [20]	Urban waste management	MIP model for municipal waste in Hong Kong
Sun et al. (2016)	Urban waste management	A model for municipal solid waste collection centers
Das et al. (2015) [21]	Urban waste management	A model for waste management objective function to minimize the cost of collecting and transporting the waste system
Giovanni Lopez et al. (2015)	Urban waste management	The goal is to maximize profits by reducing the cost of transporting and selling recyclable materials in Brazil

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Table 2 Literature review for the reverse logistic network design

Reverse		**Solution Method**		**Operational Risk**		**Network**		**Objective Function**		**Issue**		
Repair	**Recycling**	**Metaheuristics**	**Exact Method**	**Uncertainty**	**Failure**	**Multi-Period**	**Multi Product**	**Environmental Effects**	**Cost**	**Year**	**Author(s)**	**Row**
	*		*	*		*	*		*	2014	Ramezani et al.	**1**
*	*		*	*		*	*		*	2014	J. Zeballos	**2**
*	*			*			*		*	2012	Tarokh et al.	**3**
			*				*	*	*	2014	Tarokh and ghayeblu	**4**
		*				*			*	2012	Olivares-Benitez	**5**
*	*	*		*		*	*		*	2012	Romanian	**6**
		*	*		*		*		*	2013	manavizade	**7**
	*	*		*			*		*	2015	Zahedi et al.	**8**
				*		*		*	*	2018	Rahimi and Ghezavati [40]	**9**
*		*					*	*	*		**Proposed Research**	**10**

In traditional forward logistics systems, environmental considerations have not been included or have been considered less. The system has been strongly focused on minimizing costs and increasing profits. Considering environmental responsibilities from the logistics perspective, the management horizon has been expanded by a new goal of minimizing the total environmental effects. To achieve this, the goal of management is required to evaluate the environmental effects in the system to balance the traditional costs such as material transportation costs and storage costs, as well as the costs related to environmental requirements and related benefits. The activities related to new environmental responsibilities may be very costly, but on the other hand, the expansion of the market share partially compensates for this increment in cost.

After analyzing the existing literature related to the reverse logistics of waste management, the proposed model has used reverse logistics and waste management together to reduce the environmental effects.

In the proposed model, products that are at the end of their life or products that can no longer be used are collected and returned to their life cycle, or their parts are reused. If they are not usable, they are safely destroyed to have minimum effect on the environment.

Finally, in the presented model, the costs reduction in each facilities (for different activities such as the transportation, environmental, facility construction, warranty, and operation) was the main goal. According to the conducted studies, there is no model with the presented assumptions that reduces the entire reverse logistics network and environmental costs, simultaneously.

So, in this study, the environmental costs with reverse logistics network are considered together and the model is solved using numerical examples.

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2 Problem description and assumption

This section provides a detailed problem description and the assumptions for the designed reverse logistics network.

The problem definition of reverse logistics network design for electronic waste management is shown in Fig 1.

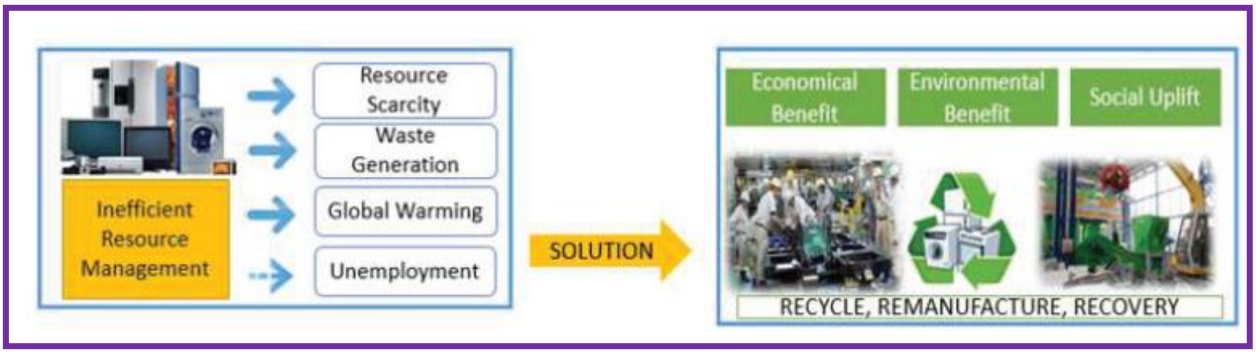

Fig 1 Reverse logistics network design for e-waste management

2.1 The proposed Model Assumptions

1. The model is multi-product and eleven-level;
2. The position of the collecting center and the customer center is clear;
3. The quality of the returned products is not clear;
4. The quality of the repaired products and new products is not at the same level;
5. Facilities include centers (collection, inspection and control, separation and disassembly, repair, and recovery, new spare store (parts manufacturer),manufacturing factory, customer, plastic parts collection center, metal parts collection center, electronic parts collection center, and safe disposal).
6. Network costs include (facility-established costs, transportation costs between facilities and operating costs in each facility, and environmental impact costs in construction, facility and transportation processing, and guarantee costs).
7. The cost and amount of CO_2 emissions from transportation and established operations in facilities are clear and definite.
8. The warranty price for the products is assumed to be fixed.

This model is concerned with minimizing the costs of the network design under the uncertainty of the product price returned from the recovery/repair center. Obtaining the optimal level of sending and receiving from each facility is regarded as the secondary objective of the research. Generally, the following objectives are achieved after solving the model:

1. The optimal place for the facilities
2. The level of sending and receiving facilities
3. Optimizing the costs of the chain, and etc.

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2.2 Definition of the mathematical model

The network studied in the present work is a reverse logistics network that can support various industries in which the products are recovered and recycled at the end of their shell life.

In this research, a reverse logistics network model has been considered for the products returned from the recovery/repair center to minimize the costs of establishing the centers, operations, and transportation. The proposed model specifies which centers of inspection/control,recovery/repair,separation/dismantling,plastic spare center, metal spare center, electronic spare center, manufacture factory, new spare store, and safe destroy should be opened. Moreover, the best strategy for transporting the products and pieces required by the facilities is determined to minimize the transportation cost.

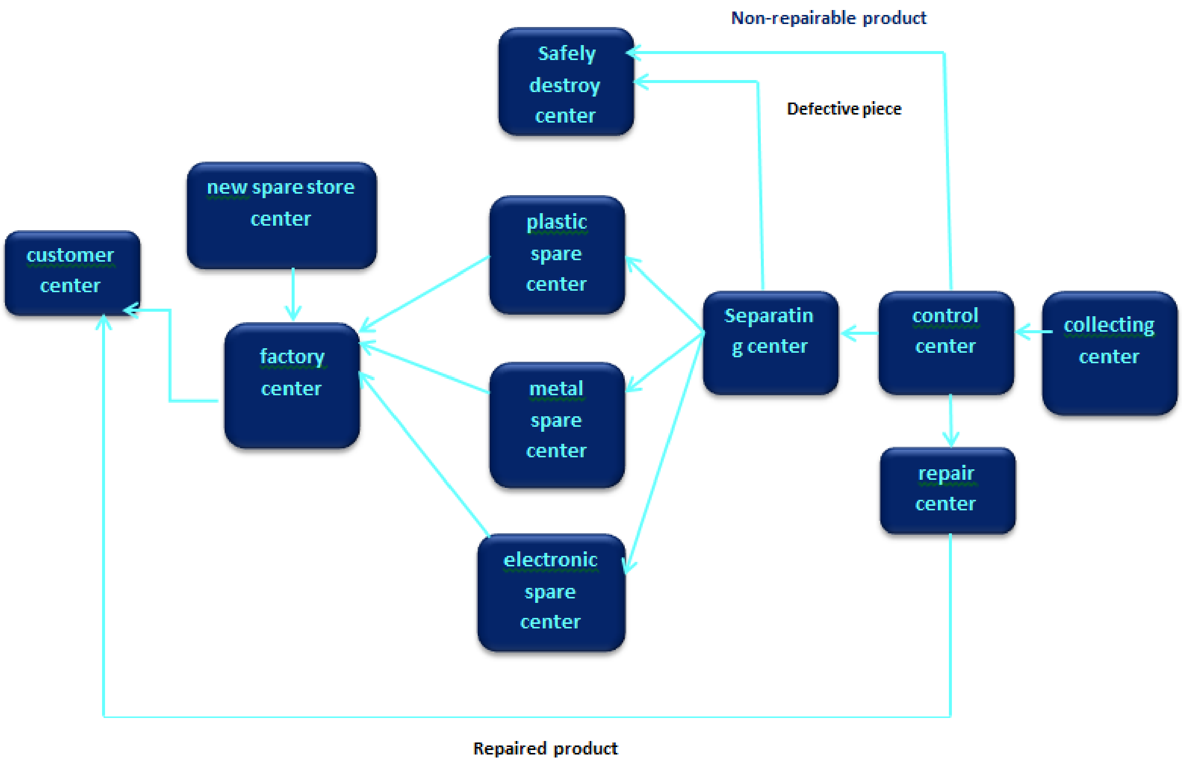

Fig 2 Network structure for the reverse logistic

2.3 Mathematical Modeling

The proposed model can be formulated as follows:

Table 3 Sets

I	Set of collecting centers	I ϵ I
J	Set of inspection/control centers	j ϵ J
K	Set of separation/dismantling centers	k ϵ K

L	Set of recovery/repair centers	l ϵ L
P	Set of plastic center	p $\in P$
M	Set of metal spare center	m ϵ M
E	Set of electronic spare center	e$\in E$
N	Set of safely destroy centers	n ϵ N
F	Set of the factory center	f $\in F$
O	Set of new spare store center	o ϵ O
Y	Set of customer centers	y ϵ Y
H	Set of all products	p ϵ P
S	Set of all pieces	s ϵ S

Table 4 Indexes

I	Index of collecting centers	I ϵ I
J	Index of inspection/control centers	j ϵ J
K	Index of separation/dismantling centers	k ϵ K
L	Index of recovery/repair centers	l ϵ L
P	Index of plastic center	p $\in P$
M	Index of metal spare center	m ϵ M
E	Index of electronic spare center	e$\in E$
N	Index of safely destroy centers	n ϵ N
F	Index of the factory center	f $\in F$
O	Index of new spare store center	o ϵ O
Y	Index of customer centers	y ϵ Y
H	Index of all products	p ϵ P
S	Index of all pieces	s ϵ S
PP	Index of the plastic piece	pp ϵPP
Mp	Index of the metal piece	mpϵMP
EP	Index of electronic piece	epϵEP

Table 5 Parameters

$\boldsymbol{f_i}$	cost of establishing a collecting center
$\boldsymbol{g_j}$	cost of establishing a control center

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bs_k	cost of establishing a separating center
bo_l	cost of establishing a repair center
So_p	cost of establishing a plastic spare center
So_m	cost of establishing a mental center
So_e	cost of establishing an electronic center
b_n	cost of establishing destroy the center
d_f	cost of establishing a factory center
a_o	cost of establishing a new spare store center
e_y	cost of establishing a customer center
gu_h	cost of product guaranty
Ic_i	the maximum amount of receive in the collecting center
Jc_j	the maximum amount of receive in a control center
Kc_k	the maximum amount of receive in separating center
Lc_l	the maximum amount of receive in the repair center
Pc_p	the maximum amount of receive in plastic spare center
Mc_m	the maximum amount of receive in the metal spare center
Ec_e	the maximum amount of receive in the electronic spare center
Nc_n	the maximum amount of receive in the destroyed center
Fc_f	the maximum amount of receive in the factory center
Oc_o	the maximum amount of receive in the new spare store center
Yc_y	the maximum amount of receive in the customer center
Io_i	cost of operation in the collecting center
Jo_j	cost of operation in the control center
Ko_k	cost of operation in separating center
Lo_l	cost of operation in the repair center
Po_p	cost of operation in the plastic spare center
Mo_m	cost of operation in the metal spare center
Eo_e	cost of operation in the electronic spare center
No_n	cost of operation in destroying center
Fo_f	cost of operation in the factory center
Oo_o	cost of operation in the new spare store center
Yo_y	Cost of operation in the customer center
B_h	price of repair product
S_h	price of produce product
L_h	percent of the repairable product
K_h	percent of useable product
N_h	percent of unusable product
O_s	percent of the usable piece
N_s	percent of the unusable piece
R_h	amount of returned product
co_2^{cap}	allowed amount of emission CO2
α	cost of emission allowed limit CO2
E	Gas emission factor in transportation
d_{ij}	distance between the collection center and the control center
d_{jn}	distance between the control center and destroy center
d_{jl}	distance between the control center and the repair center
d_{jk}	distance between the control center and the separate center
d_{kn}	distance between the separate center and destroy center
d_{kp}	distance between the separate center and the plastic center
d_{km}	distance between the separate center and metal center
d_{ke}	distance between the separate center and the electronic center
d_{pf}	distance between the plastic center and the factory center

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d_{mf}	distance between the metal center and the factory center
d_{ef}	distance between the electronic center and the factory center
d_{kf}	distance between the new spare center and the factory center
d_{fy}	distance between the factory center and the customer
d_{ly}	distance between the repair center and the customer
P_{ijh}	cost of product transportation between the collecting center and control center
I_{jlh}	cost of product transportation between the control center and the repair center
D_{jkh}	cost of product transportation between the control center and the separating center
T_{kns}	cost of piece transportation between the separation center and destroy the center
N_{jnh}	cost of product transportation between the control center and destroy the center
A_{kps}	cost of piece transportation between separating center and plastic spare center
F_{lyh}	cost of product transportation between the repair center and customer center
K_{pfs}	cost of piece transportation between the plastic spare center and factory center
L_{mfs}	cost of piece transportation between the metal spare center and factory center
O_{efs}	cost of piece transportation between the electronic spare center and factory center
E_{fyh}	cost of product transportation between the factory center and customer center
B_{kms}	cost of piece transportation between the separate center and mental center
C_{kes}	cost of piece transportation between the separate center and electronic center
H_{ofs}	cost of piece transportation between new spare store center and factory center
K_{hs}	coefficient usage piece in products
D_{yh}	amount of demand customer center
h_s	the product that uses pieces on them

Table 6 Decision variables

X_{ijh}	amount of production that are sent from the collecting center to the control center
U_{jlh}	amount of production that are sent from the control center to the repair center
W_{jnh}	amount of production that are sent from the control center to destroy the center
B_{jkh}	amount of production that are sent from the control center to the separate center
C_{kns}	amount of pieces that are sent from separate centers to destroy the center
V_{kppp}	amount of pieces that are sent from separate centers to the plastic center
M_{kms}	amount of pieces that are sent from separate centers to mental center
N_{kes}	amount of pieces that are sent from separate centers to the electronic center
T_{pfpp}	amount of pieces that are sent from the plastic center to the factory center
Z_{mfmp}	amount of pieces that are sent from the mental center to the factory center
H_{efef}	amount of pieces that are sent from the electronic center to the factory
Q_{ofs}	amount of pieces that are sent from the new spare center to the factory
K_{fyh}	amount of production that are sent from the factory center to the customer center

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$\boldsymbol{S_{lyh}}$	amount of production that are sent from the repair center to the customer center
$\boldsymbol{co_h}$	emission amount of CO_2 in the reverse logistic network for production
$\boldsymbol{Ck_s}$	emission amount of CO_2 in the reverse logistic network for the piece
$\boldsymbol{Co_2}$	emission amount of CO_2 in the reverse logistic network
$\boldsymbol{qp_{ofpp}}$	amount of piece pp that are sent from the new spare center to the factory center
$\boldsymbol{qm_{ofmp}}$	amount of piece mp that are sent from the new spare center to the factory center
$\boldsymbol{qe_{ofep}}$	amount of piece ep that are sent from the new spare center to the factory center
$\boldsymbol{MR_{kmp}}$	Number of the metal piece in a separate center
$\boldsymbol{ER_{kep}}$	Number of the electronic pieces in a separate center
$\boldsymbol{PR_{kpp}}$	Number of the plastic pieces in a separate center

Table 7 Binary variables

C_j^{co}	1 : if the control center is established at point *j*; 0 : otherwise
C_k^{co}	1 : if the separation/dismantling center is established at point *k*; 0 : otherwise
C_l^{co}	1 : if a recovery/repair center is established at point *l*; 0 : otherwise
C_o^{co}	1 : if a new spare center is established at point *o;* 0 : otherwise
C_m^{co}	1 : if the metal center is established at point *m*; 0 : otherwise
C_f^{co}	1 : if the factory center is established at point *f*; 0 : otherwise
C_n^{co}	1 : if a safe discarding center is established at point n; 0 : otherwise
C_p^{co}	1 : if a plastic center is established at point p; 0 : otherwise
C_e^{co}	1 : if an electronic center is established at point e; 0 : otherwise

2.4 Formulation of the mathematical model

2.4.1 Objective function

Considering the minimization of costs, a model should be presented to minimize the following costs simultaneously:

- Establishment cost of facilities
- Transporting cost of pieces and products between facilities
- Operating cost in each unit of facilities
- Cost of emission CO_2 ….

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- Cost of guaranty

$$
\begin{aligned}
\mathrm{MinZ} = {} & \sum_{j\in J} C_j^{co} g_j + \sum_{k\epsilon K} C_k^{co} bs_k + \sum_{l\epsilon L} C_l^{co} b_i + \sum_{f\epsilon F} C_f^{co} d_f + \sum_{p\epsilon P} C_P^{co} So_p + \sum_{m\epsilon M} C_m^{co} So_m + \sum_{e\epsilon E} C_e^{co} So_e \\
& + \sum_{n\epsilon N} C_n^{co} b_n + \sum_{i\in I}\sum_{j\in J}\sum_{h\in H} X_{ijh} P_{ijh} + \sum_{j\in J}\sum_{l\in L}\sum_{h\in H} U_{jlh} I_{jlh} + \sum_{l\in L}\sum_{y\in Y}\sum_{h\in H} W_{lyh} F_{lyh} \\
& + \sum_{j\in J}\sum_{k\in K}\sum_{h\in H} B_{jkh} D_{jkh} + \sum_{k\in K}\sum_{n\in N}\sum_{s\in S} C_{kns} T_{kns} \\
& + \sum_{k\in K}\sum_{p\in P}\sum_{s\in S} V_{kps} A_{kps} + \sum_{k\in K}\sum_{m\in M}\sum_{s\in S} M_{kms} B_{kms} \\
& + \sum_{k\in K}\sum_{e\in E}\sum_{s\in S} N_{kes} C_{kes} + \sum_{p\in P}\sum_{f\in F}\sum_{s\in S} T_{pfs} K_{pfs} + \sum_{m}\sum_{f}\sum_{s} Z_{mfs} L_{mfs} \\
& + \sum_{e\in E}\sum_{f\in F}\sum_{s\in S} H_{efs} O_{efs} + \sum_{o\in O}\sum_{f\in F}\sum_{s\in S} Q_{ofs} H_{ofs} \\
& + \sum_{f\in F}\sum_{y\in Y}\sum_{h\in H} K_{fyh} E_{fyh} + \sum_{l\in L}\sum_{y\in Y}\sum_{h\in H} S_{lyh} F_{lyh} + \sum_{j\in J}\sum_{l\in L}\sum_{p\in P} JO_j X_{jlp} \\
& + \sum_{j\in J}\sum_{l\in L}\sum_{h\in H} Lo_l U_{jlh} + \sum_{j\in J}\sum_{k\in K}\sum_{h\in H} ko_k B_{jkh} \\
& + \sum_{j\in J}\sum_{n\in N}\sum_{k\in K}\sum_{n\in N} No_n (W_{jnh} + C_{kns}) + \sum_{k\in K}\sum_{p\in P}\sum_{s\in S} Po_p V_{kps} + \sum_{k\in K}\sum_{m\in M}\sum_{s\in S} Mo_m M_{kms} \\
& + \sum_{k\in K}\sum_{e\in E}\sum_{s\in S} Eo_e N_{kes} + \sum_{f\in F}\sum_{p\in P}\sum_{s\in S}\sum_{o\in O} Fo_f (T_{pfs} + Z_{mfs} + H_{efs} + Q_{ofs}) \\
& + \sum_{f\in F}\sum_{y\in Y}\sum_{l\in L}\sum_{h\in H} Yo_y (K_{fyh} + S_{lyh}) + \alpha\left(co_2 - co_2^{cap}\right) + Qu_h
\end{aligned}
$$

2.4.2 Constraints

2.4.2.1 Capacity Constraints

This limitation states that the amount of product returned from the sending center to the recipient must be smaller than the capacity of the receiving center.

The capacity constraint in Equation (1) shows that the amount of product returned from the collection unit to the inspection and control unit must be smaller than the capacity of the inspection and control center.

$$\sum_{i\in I}\sum_{h\in H} X_{ijh} \le jc_j C_j^{co} \qquad \forall j \tag{1}$$

$$\sum_{j\in J}\sum_{h\in H} D_{jkh} \le Kc_k C_k^{co} \qquad \forall k \tag{2}$$

$$\sum_{j\in J}\sum_{h\in H} U_{jlh} \le Lc_l C_l^{co} \qquad \forall l \tag{3}$$

$$\sum_{k\in K}\sum_{s\in S} V_{kps} \le Pc_p C_p^{co} \qquad \forall P \tag{4}$$

$$\sum_{k\in K}\sum_{s\in S} M_{kms} \le M_{cm} C_m^{co} \qquad \forall M \tag{5}$$

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$$\sum_{k\in K}\sum_{s\in S} N_{kes} \le Ec_e C_e^{co} \qquad \forall e \qquad 6$$

$$\sum_{p\in P}\sum_{s\in S} T_{pfs} + \sum_{m\in M}\sum_{s\in S} Z_{mfs} + \sum_{o\in O}\sum_{s\in S} H_{ofs} + \sum_{e\in E}\sum_{s\in S} Q_{efs} \le Fc_f C_f^{co} \quad \forall f \qquad 7$$

$$\sum_{f\in F}\sum_{h\in H} K_{fyh} + \sum_{l\in L}\sum_{h\in H} S_{lyh} \le Yc_y C_y^{co} \qquad \forall y \sum_{j\in J}\sum_{h\in H} W_{jnh} + \sum_{k\in K}\sum_{s\in S} C_{kns} \le Nc_n C_n^{co} \qquad \forall n \qquad 8$$

$$\sum_{i\in I}\sum_{h\in H} X_{ijh} \le jc_j C_j^{co} \qquad \forall j \qquad 9$$

$$\sum_{j\in J}\sum_{h\in H} D_{jkh} \le Kc_k C_k^{co} \qquad \forall k \qquad 10$$

2.4.2.2 Inlet and outlet balance Constraints in each center

The Inlet and outlet balance constraint in Equation (11) shows that the amount of production that is sent from the collecting center to the control center must be equal to the amount of returned product.

$$\sum_{i\in I}\sum_{j\in J} X_{ijh} = R_h \qquad \forall h \qquad 11$$

$$L_h \sum_{i\in I} X_{ijh} = \sum_{l\in L} U_{ilh} \qquad \forall h, j \qquad 12$$

$$K_h \sum_{i\in I} X_{ijh} = \sum_{k\in K} U_{jkh} \qquad \forall h, j \qquad 13$$

$$N_n \sum_{i\in I} X_{ijh} = \sum_{n\in N} W_{jnh} \qquad \forall h, j \qquad 14$$

$$L_h \sum_{j\in J} U_{jlh} = \sum_{y\in Y} S_{lyh} \qquad \forall\, l, h \qquad 15$$

$$\sum_{h\in H} B_{jkh} = \sum_{p\in P} V_{kps} + \sum_{m\in M} M_{kms} + \sum_{n\in N} C_{kns} + \sum_{e\in E} N_{kes} \qquad \forall\, k, s \qquad 16$$

$$\sum_{k\in K} V_{kps} = \sum_{f\in F} T_{pfs} \qquad \forall\, p, s \qquad 17$$

$$\sum_{k\in K} M_{kms} = \sum_{f\in F} Z_{mfs} \qquad \forall\, m, s \qquad 18$$

$$\sum_{k\in K} N_{kes} = \sum_{f\in F} H_{efs} \qquad \forall\, e, s \qquad 19$$

$$\sum_{p\in P}\sum_{s\in S} T_{pfs} + \sum_{m\in M}\sum_{s\in S} Z_{mfs} + \sum_{e\in E}\sum_{s\in S} H_{efs} + \sum_{o\in O}\sum_{s\in S} Q_{ofs} = \sum_{y\in Y}\sum_{h\in H} K_{fyh} \qquad \forall\, f \qquad 20$$

$$\sum_{l\in L} S_{lyh} + \sum_{f\in F} K_{fyh} = D_{yh} \qquad \forall\, y, h \qquad 21$$

2.4.3 CO_2 emission for transportation

2.4.3.1 CO_2 emission for production transportation

This limitation shows that the amount of gas emission CO_2 caused by the transportation of products must be equal to the emission amount CO_2 in the reverse logistic network for production.

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$$E[\sum_{i\in I}\sum_{j\in J}\sum_{h\in H} d_{ij}X_{ijh} + \sum_{j\in J}\sum_{n\in N}\sum_{h\in H} d_{jn}W_{jnh} + \sum_{j\in J}\sum_{l\in L}\sum_{h\in H} d_{jn}U_{jlh} + \sum_{j\in J}\sum_{k\in K}\sum_{h\in H} d_{jk}B_{jkh} + \sum_{f\in F}\sum_{y\in Y}\sum_{h\in H} d_{fy}k_{fyh} + \sum_{l\in L}\sum_{y\in Y}\sum_{h\in H} d_{ly}S_{lyh}] = \mathrm{Co(h)}$$

2.4.3.2 CO_2 emission for piece transportation

This limitation shows that the amount of gas emission CO_2 due to the transportation of parts must be equal to the emission amount of CO_2 in the reverse logistic network for the piece.

$$E[\sum_{k\in K}\sum_{n\in N}\sum_{s\in S} d_{kn}C_{kns} + \sum_{k\in K}\sum_{p\in P}\sum_{s\in S} d_{kp}V_{kps} + \sum_{k\in K}\sum_{m\in M}\sum_{s\in S} d_{km}M_{kms} + \sum_{k\in K}\sum_{e\in E}\sum_{s\in S} d_{ke}N_{kes} + \sum_{p\in P}\sum_{f\in F}\sum_{s\in S} d_{pf}T_{pfs} + \sum_{m\in M}\sum_{f\in F}\sum_{s\in S} d_{mf}Z_{mfs} + \sum_{e\in E}\sum_{f\in F}\sum_{s\in S} d_{ef}H_{efs} + \sum_{o\in O}\sum_{f\epsilon F}\sum_{s\epsilon S} d_{of}Q_{ofs}] = \mathrm{Ck(s)}$$

2.4.3.3 CO_2 emission for transportation in the network

$$Co(h) + Ck(s) = CO2$$

2.4.3.4 Non-negativity limitations

$$X_{ijh}, W_{jnh}, U_{jlh}, B_{jkh}, C_{kns}, V_{kps}, M_{kms}, N_{kes}, T_{pfs}, Z_{mfs}, H_{efs}, Q_{ofs}\ K_{fyh}, S_{lyh} \geq 0 \quad \forall \quad i,j,k,l,o,m,n,y,s,p,e,f,h$$

2.4.3.5 One and zero limitations:

$$C_j^{co} = \{0,1\} \quad \forall j \qquad C_f^{co} = \{0,1\} \quad \forall f \qquad C_n^{co} = \{0,1\} \quad \forall n$$
$$C_k^{co} = \{0,1\} \quad \forall k \qquad C_p^{co} = \{0,1\} \quad \forall p$$
$$C_l^{co} = \{0,1\} \quad \forall l \qquad C_m^{co} = \{0,1\} \quad \forall m$$
$$C_o^{co} = \{0,1\} \quad \forall o \qquad C_e^{co} = \{0,1\} \quad \forall e$$

2.5 Numerical example

In this research, a numerical example has been presented to evaluate the accuracy of the model and solve it. The model has been solved by presenting two products and three pieces. All the parameters have been entered into the model as numerical data

Table 7 Set of points present

Sets	Centers
Set of collecting centers	I_1 ,I_2 ,I_3
Set of inspection/control centers	J_1 , J_2
Set of separation/dismantling centers	K_1,K_2,K_3
Set of recovery/repair centers	L_1 ,L_2
Set of plastic center	P_1,P_2

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Set of metal spare center	M_1 ,M_2
Set of electronic spare center	E_1,E_2
Set of safely destroy centers	N_1 ,N_2
Set of the factory center	F_1,F_2,F_3
Set of new spare store center	O_1 ,O_2 ,O_3
Set of customer centers	Y_1 ,Y_2
Set of all products	H_1 H_2
Set of all pieces	S_1 ,S_2 ,S_3

Table 8 Maximum amount of received in each Center

Center	**Amount**
Collecting centers	**I1=300 ,I2=250 ,I3=290**
inspection/control centers	**J1=320 ,J2=350**
Separation Center	**K1=300 ,K2=280 ,K3=260**
Repair Center	**L1=320 ,L2=310**
Plastic center	**P1=230,P2=250**
Metal spare center	**M1=280 ,M2=290**
Electronic spare center	**E1=300 ,E2=280**
Safely destroy centers	**N1=200 ,N2=180**
Factory center	**F1=250 ,F2=260 ,F3=240**
Spare store center	**O1=400 ,O2=380 ,O3=350**
customer centers	**Y1=70000000 ,Y2=60000000**

3 The optimal result of the network

Above mentioned data has been entered into GAMS software as input and the considered values have been obtained from the variables. For instance, a response (result) table is presented as follows:

Table 9 Amount of production that is sent from the collecting center to the control center

X(I,J,H)	i1.j1.h1	i1.j1.h2	i1.j2.h1	i1.j2.h2	i2.j1.h1	i2.j1.h2	i2.j2.h1	i2.j2.h2	i3.j1.h1	i3.j1.h2	i3.j2.h1	i3.j2.h2
	0	0	0	0	0	0	130	220	170	60	0	0

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Table 10 Establish control center in point j

C_j^{co}	Amount
J1	1
J2	1

This table shows that J1 and J2 control centers should be established at both points.

Table 11 CO_h emission amount CO_2 in the reverse logistic network for production

CO_1	1,128,045
CO_2	10,342,040

Table 12 Objective function

Objective Function	$2.426*10^{11}$

4 Data analysis

4.1 Sensitivity analysis

A sensitivity analysis is performed on some major parameters used in the proposed model for reverse logistics network design by changing the values of parameters with a certain value. The variations of the costs that are considered in the sensitivity analysis are revealed in Table 13. The effect of that change on the value of the objective function is shown in Table 13.

Table 13 Sensitivity analysis of the key parameters

Parameter	Percentage change	Objective Function
The cost of establishing destroy center	20%	$4.69*10^{11}$
	-20%	$4.696*10^{11}$
	40%	$4.697*10^{11}$
	-40%	$4.696*10^{11}$
Cost of operation in the control center	20%	$4.696*10^{11}$
	-20%	$4.696*10^{11}$
	40%	$4.696*10^{11}$
	-40%	$4.696*10^{11}$
Cost of emission allowed limit CO_2	20%	$5.558*10^{11}$
	-20%	$3.834*10^{11}$
	40%	$6.421*10^{11}$
	-40%	$2.972*10^{11}$

In Fig 3, the sensitivity analysis of the cost of emission allowed limit CO_2 change parameter is given in the form of a diagram.

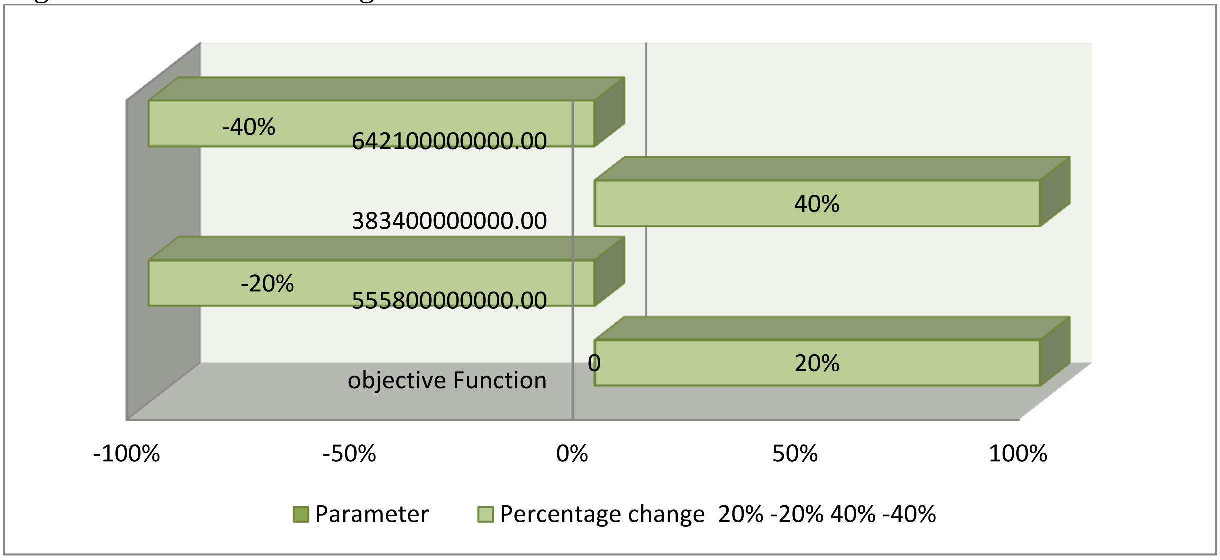

Fig 3 Objective Function change with cost of emission allowed limit co_2 change

Also, to study the model, we solved the model with different data, the results of which are as follows:

The first case:

In the first case, the number of facilities (such as the number of factory centers, new spare store centers) are changed and the model is solved, accordingly. The Optimal results of the Network are shown in Table 14 and Table 15.

Table 14 The Optimal Result of the Network in the first case

Objective Function	$2.29*10^{14}$

Table 15 CO_h Emission amount CO_2 in the reverse logistic network for production

CO1	1,106,780
CO2	1,056,018

The Second case:

In the second case, we change the number of facilities and amount of received pieces and costs then solve the model again and the results are shown in Table 16 and Table 17.

Table 16 The Optimal Result of the Network in the second case

Objective Function	$4.199 *10^{14}$

Table 17 CO_h Emission amount co2 in the reverse logistic network for production

CO_1	25,900
CO_2	1,745,500

5 Conclusions

In this research, a mixed integer linear programming model for a reverse logistics network for return products is presented,

The proposed model is consisted of eleven-levels, multi-procurement and multi-part network including collection centers, inspection and maintenance, separation and disassembly, plastic parts center, metal parts and electronic parts, new parts center and manufacturing plant, customer center and destruction center.This model seeks to minimize the costs of the entire system. These costs include the costs of transporting products and parts, the cost of building facilities, the cost of environmental impacts, and the cost of warranty. This model collects the products that are at the end of life or cannot be used, or the products which their parts can be used will help to reduce the environmental effects. In addition, the reproduced product in the reverse logistics network can reach the customers at a lower price, which is also important for the profit of production. The proposed model was solved by GAMS software and the results were presented with some numerical examples. Acceptable results were obtained by changing facilities, capacity values, etc. The number of metal-plastic-electronic products and parts that are sent from each center to another center, the amount of each piece and product and the construction or non-construction of Hari pack facilities were obtained.

This model is practical and can support industries whose products are at the end of their life. The advantage of this method is that manufacturing organizations can establish reverse logistics in their organization and network design such as research reduce their costs dramatically. Also, with the help of the mentioned software, they can have all the changes in their hands after modeling numerically.

6 Recommendations

Due to the need for research on environmental concerns, manufacturers of certain products (such as automakers, paper, glass, plastics, etc.) are recommended to use reverse logistics network design models in their company's processes. To have a more efficient and flexible supply chain to be able to reduce environmental pollution and to use the products collected from customers as a raw material of their production cycle, which in this way costs reduce their production. In addition to safely disposing of waste, they also follow the rules of green logistics.

Consumers are also advised to collect consumed products whose presence in nature causes environmental pollution and is not compatible with nature and to cooperate with companies familiar with logistics processes. They can buy remanufactured products with a quality almost identical to the quality of the original product and at a lower price.

1. The same uncertainty conditions can be used for a closed-loop network.
2. In recent years, special attention has been paid to goals such as responsiveness and network stability. Considering them in network design models can be very attractive.
3. Uncertainty can also be expressed in the cost of transportation.

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4. The same model can be solved with solid optimization.
5. In addition to environmental impacts, economic and social impacts of waste can also be considered in the network design model.

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