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Designing a sustainable-resilient supply chain network with an emphasis on financing and investment decisions using the NSGA-II algorithm

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Abstract

Nowadays, product recovery and waste recycling are receiving more attention in order to reduce environmental pollution and production costs in the form of a closed-loop and sustainable supply chain. Also, designing a supply chain by considering resilience approaches can protect buyers against disruptions such as natural, human or technological disasters. On the other hand, efficient and effective financial supply chain management (FSCM) way is known as one of the main structures in line with the continuity and stability of the chain's performance, and budget restrictions are of great importance considering the issue of scarcity of resources in the economy. This study has presented a multi-objective mixed integer linear programming (MOMILP) model of a single-period, multi-product and multi-level closed-loop supply chain, taking into account the dimensions of sustainability and resilience, emphasizing the balance between the initial budget and the cost of establishing facilities under uncertainty. subsequently, to eliminate the uncertainty of the demand parameters and costs, its robust counterpart was presented based on Pishvaee's robust possibilistic programming (RPP) model. The augmented Epsilon Constraint method (AEC) and Non-dominated Sorting Genetic Algorithm (NSGA-II) were used to solve and evaluate it.

Keywords: supply chain, resilience, sustainability, robust optimization
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1 Introduction

Supply chain refers to a network consisting of various facilities, including suppliers, production centers, distribution, etc., which includes all transportation and storage of raw materials, semi-finished products, and final products from

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the seller to the final customer [6] and design Its suitability with regard to physical and financial flows brings its effective management and profitability in addition to creating a competitive advantage [1]. Also, in the past, most economic aspects were considered in the configuration of the supply chain network; but the sustainability criteria in the design of the supply chain network were taken into consideration with the increase of social and environmental concerns, [3] because sustainable supply chain management is a management process that combines environmental considerations, social performance and economic participation together [34] and it can moderate the negative effects on the society and the environment [12]. The increase in the complexity of the supply chain due to natural disasters or the increase in outsourcing, the increase in uncertainty in demand, etc., has led to its vulnerability and the occurrence of these events, even in a distant place, can cause disruptions on a large scale, and resilience in terms of It is taken as a response to reduce the destructive effects of these disruptions in the supply chain [2]. In other words, resilience prepares the chain for any event so that it has the ability to return to the initial or more favorable state after the disturbance while providing an efficient and effective response to disturbances [19]. Early efforts to integrate resilience concepts date back to 1995 [35]. The researchers found out that the combination of two approaches of sustainability and resilience in the supply chain can improve its performance [15, 20] and some others described the use of disruption management strategies as well as the reduction of environmental effects as the basic need in the supply chain [40]. Patidar et al [26] proposed the integration of resilience and sustainability in the automotive supply chain. A group of researchers emphasized the integration of two resilience and sustainability approaches as well as carrying out further research in this area due to the recent disasters in the world [23, 28, 30].

The budget constraint and financial resources are raised as another issue in the design of the supply chain network, which can be an effective factor in not using the appropriate number of facilities to provide services in the supply chain. The budget constraint is considered as the first part of the profit maximization framework and describes all the combinations of goods and services that the consumer can provide. Therefore, the total costs of designing the supply chain network cannot exceed the available financial resources [17]. On the other hand, improving the level of services in the supply chain requires the necessary financing and budget management to establish, launch and maintain facility operations. In this regard, Shapiro emphasized the high interaction and connection of financial flows and decisions with supply chain planning [33]. In general, research shows the positive impact of appropriate financial decisions on the level of service provided in the supply chain, and can improve the response to customer needs.

The budget constraint is considered as an inhibiting factor in the establishment of facilities in the design of the supply chain network, which in some cases can lead to a reduction in services and make it difficult to respond to disruptions in the supply chain[7]. Taking a loan increases the budget and thus increases the ability to establish facilities. In this regard, increasing facilities can improve the level of response to customers' needs, stability and resilience. For this reason, it is very important to pay attention to the balance between the budget and the amount of investment in the establishment of facilities in order to improve service delivery and build a resilient supply chain.

According to what was said, the innovation of this research is the combination of sustainability and resilience in the closed-loop supply chain and emphasis on environmental aspects and financial and investment decisions in the construction and establishment of facilities in the presented model at the same time.

The first part of this study presents an introduction to the sustainable and resilient supply chain, as well as the importance of financial management in the design of the supply chain network, and the second part describes the research background. Moreover, the mathematical model of the problem is presented in the third section, the fourth section presents the solving method, and the research results and suggestions are provided in the fifth section.

2 Research background

Different researchers emphasized the integration of resilience and sustainability concepts in the supply chain [5, 20, 26, 29, 40]. Nevertheless, most papers have been proposed since 2019, suggesting the integration of sustainability and resilience concepts at the early stages of development, a new topic for research [3]. Furthermore, many decisions at the strategic level of the supply chain are financial in nature and must be integrated with other decisions [33]. Kaur and Singh [11] proposed a mathematical model with definitive data for the resilient and sustainable forward supply chain network. This study's results revealed that the proposed model reduced supply costs under limited carbon emissions. Zahiri et al [37] presented a mathematical model for the resilient and sustainable supply chain network and developed a new fuzzy random programming model to deal with data uncertainty. Mousavi Ahranjani et al [21] presented a mathematical model for the forward supply chain network considering the resilience and sustainability dimensions and employed a potential random programming approach to cope with the existing uncertainties. Zamanian et al [38] presented a resilient and sustainable supply chain mathematical model aiming at minimizing cost, harmful environmental effects, and low capacity-related penalties, as well as maximizing service levels and solved it with the

Epsilon Constraint method. Hosseini Motlagh et al [8] presented a robust resilient and sustainable mathematical model for an electricity supply chain network. According to the results, with a 50% increase in costs, social responsibility, and network resilience respectively increase by 50% and 20% . Sazvar et al [32] during a study tried to minimize costs, pollution and lost sales opportunities and maximize job opportunities in their proposed supply chain network. Also, they considered additional capacity for suppliers and maximizing customer service levels as resilience strategies, and solved the model using Goal Programming. In their mathematical model, Zare Mehrjerdi and Shafiee [39] utilized multiple sourcing strategies, shared information for resilience and minimization of costs, energy consumption, pollution, and maximization of job opportunities for sustainability of the supply chain, and solved it through using the Epsilon Constraint method. Lotfi et al [16] presented a robust two-stage stochastic optimization model for the electricity supply chain network. In this network, renewable energies are employed when the demand increases, making it resilient and stochastic. Sadeghi et al [30] presented a robust mathematical model for the resilient and sustainable forward supply chain network and solved it using the Epsilon Constraint method. Moreover, Nayeri et al [22] solved their robust mathematical model of a resilient and sustainable supply chain with Multi-Choice Meta-Goal Programming Associated with a Utility Function. Nickel et al [24] designed a model that in addition to the physical decisions of the supply chain network design, can make financial decisions in the field of necessary investments in order to establish facilities and also choose the appropriate loan from among the options related to getting a loan. Longinidis and Georgiadis [14] considered the financial situation and the ability to pay debts as two critical factors in the company's financial situation. The proposed model has paid attention to the integration between the design of the supply chain network and the financial and credit situation and the budget in the conditions of economic uncertainty. Jabbarzadeh et al. [10] designed a supply chain network under conditions of uncertainty. In this study, the researchers considered the disruption in the construction of facilities due to budget restrictions. Haghjoo et al [7] in the study of self, investigated financing and budget limitations in the location and establishment of facilities and its impact on supply chain disorders.

Despite researchers' emphasis on integrating the concepts of sustainability and resilience in the supply chain [5, 20, 26, 29, 40]; But few studies have investigated this issue [3, 23, 25, 36]. Studies revealed that researchers in the environmental dimension had mostly sufficed to minimize the emission of greenhouse gases, while industries are among the key consumers of energy and water. Besides, in some researches, the dimension of social responsibility has been weak or ignored. Also in the field of resilience, the strategy of using backup suppliers under the disruption condition is less considered. Previous studies have mostly taken into account the forward supply chain, while the closed-loop supply chain network supports the environment by considering different operations such as modification, reuse, remanufacturing, and recycling, as well as burying the returned products [31]. In other words, most of the research studies improve the financial performance of the supply chain, and less research has investigated the financial decisions in the construction and establishment of supply chain facilities [9]. In addition, most researchers have considered the parameters of the problem as deterministic, while in reality the parameters have high fluctuations and dynamic nature, and this affects the structure of the network design. Also, less attention has been paid to the financial aspect, along with sustainability and resilience in the supply chain. Hence, in the previous researches, the basic gap is the lack of a reliable mathematical model of a closed-loop and suitable supply chain at several levels based on the sustainability approach corresponding to the economic stakeholders' objectives, leading to a significant change in environmental and social effects, and reducing the vulnerability of the chain against disruptions according to the resilience approach and the aspects of financial management should also be taken into consideration.

3 Problem description

This research is aimed at providing a multi-objective mixed integer linear programming model of the closed-loop supply chain network, considering the dimensions of stability and resilience under conditions of uncertainty. According to Fig. 1, in the forward path, the raw materials are provided by the suppliers, converted into final products based on the manufacturing formula in production centers and sent to the retail stores by the distribution networks. The returned products are collected on the way back, and after inspection, unusable products are sent to disposal centers while the rest are sent to repair centers to be reused. In the repair centers, after partial modification, the high-quality products are sent to the production centers for reuse as first-class goods, and the products undergoing major repairs are sent to the secondary market as second-class products. Moreover, unrepairable and unusable products are sent to disposal centers. In this network, in case the suppliers cannot fulfill their responsibilities for any reason, the responsibility of supplying raw materials is taken over by the backup suppliers. Also, the cost of establishing the facility should not exceed the budget in the design of the proposed network according to the budget limit.

The Problem Assumptions

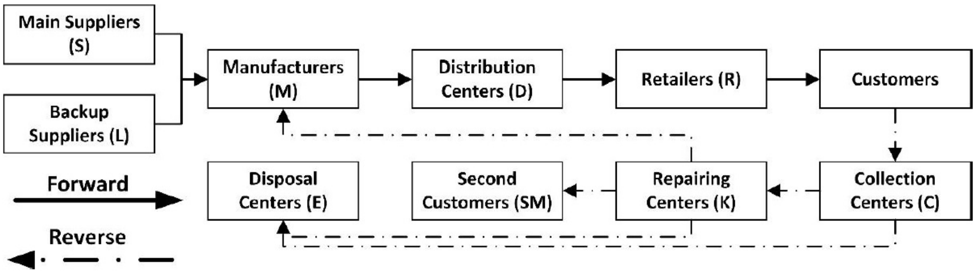


Figure 1: TProposed CLSC network

- Costs of supplying raw materials from backup suppliers are higher than from main suppliers.
- Products flow only between consecutive facilities.
- Expenses and demand quantities are considered uncertain.
- Suppliers will face performance disruptions represented by scenarios with a certain probability of occurrence, i.e. a number between zero and one.
- The capacity of the centers is already specified.
- The percentage of return products, the percentage of products sent from collection centers to repair and disposal centers, the percentage of products sent from repair centers to production centers, second markets, and disposal centers are already specified.

Model Indices

Description	**Set and Indices**	**Description**	**Set and Indices**
Main suppliers	$s \in \{1, 2, 3, ..., S\}$	Repairing Centers	$k \in \{1, 2, 3, ..., K\}$
Backup suppliers	$l \in \{1, 2, 3, ..., L\}$	Disposal centers	$e \in \{1, 2, 3, ..., E\}$
Manufacturers	$m \in \{1, 2, 3, ..., M\}$	Second customers	$sm \in \{1, 2, 3, ..., SM\}$
Distribution centers	$d \in \{1, 2, 3, ..., D\}$	products	$p \in \{1, 2, 3, ..., P\}$
Retailers	$r \in \{1, 2, 3, ..., R\}$	Raw materials	$sp \in \{1, 2, 3, ..., SP\}$
Collection Centers	$c \in \{1, 2, 3, ..., C\}$	Scenarios of disruption in suppliers	$sc \in \{1, 2, 3, ..., SC\}$
Loans receivable	$b \in \{1, 2, 3, ..., B\}$		

Model Parameters

Description	**parameters**	**Description**	**parameters**
The conversion factor of raw materials into products	hh_{sp}	Variable cost of providing the production requirements of sp by s	vcs_s^{sp}
Customer demand for the product P	d_r^p	Variable cost of producing per unit p in m	vcm_m^p
Fix cost of installing main supplier (s)	fcs_s	Amount of local employment due to construction of s	os_s^{sp}
Fix cost of installing manufacturing (m)	fcm_m	Amount of local employment due to construction of m	om_m^p
Fix cost of installing distribution center (d)	fcd_d	Amount of local employment due to construction of d	od_d^p
Fix cost of installing distribution center (d)	fcr_r	Amount of local employment due to construction of r	or_r^p

Fix cost of installing collection center (c)	fcc_c	Amount of local employment due to construction of c	oc_c^p
Fix cost of installing repairing center (c)	fck_k	Amount of local employment due to construction of k	ok_k^p
Fix cost of installing disposal center (c)	fce_e	Amount of local employment due to construction of e	oe_e^p
Variable cost of transporting unit SP from s to m	vcm_{sm}^{sp}	Water use to provide sp by s	ws_s^{sp}
Variable cost of transporting unit p from m to d	vmd_{md}^p	Water use for produce per unit p in m	wm_m^p
Variable cost of transporting unit p from d to r	vdr_{dr}^p	Water use for distribute per unit p in d	wd_d^p
Variable cost of transporting unit p from r to c	vrc_{rc}^p	Water use for distribute per unit p in r	wr_r^p
Variable cost of transporting unit p from c to k	vck_{ck}^p	Water use for allocation per unit p in c	wc_c^p
Variable cost of transporting unit p from k to e	vke_{ke}^p	Water use for repair per unit p in k	wk_k^p
Variable cost of transporting unit p from k to m	vkm_{km}^p	Water use for disposal per unit p in k	we_e^p
Variable cost of transporting unit p from k to sm	$vksm_{ksm}^p$	Amount of pollution provided unit sp by s	es_s^{sp}
Variable cost of maintaining unit p in d	vcd_d^p	Amount of pollution caused produce unit p by m	em_m^p
Variable cost of maintaining unit p in r	vcr_r^p	Amount of pollution caused maintain unit p in d	ed_d^p
Variable cost of maintaining unit p in c	vcc_c^p	Amount of pollution caused maintain unit p in r	er_r^p
Variable cost of maintaining unit p in k	vck_k^p	Amount of pollution caused maintain unit p in c	ec_c^p
Energy use for produce one unit sp by supplier	ns_s^{sp}	Amount of pollution caused repair unit p in k	ek_k^p
Energy use for produce one unit p in m	nm_m^p	Amount of pollution caused disposal unit p in e	ee_e^p
Energy use for maintain one unit p in d	nd_d^p	Amount of pollution caused by transporting product p from s to m	esm_{sm}^{sp}
Energy use for maintain one unit p in r	nr_r^p	Amount of pollution caused by transporting product p from m to d	emd_{md}^p
Energy use for maintain one unit p in c	nc_c^p	Amount of pollution caused by transporting product p from d to r	edr_{dr}^p
Energy use for repair one unit p in k	nk_k^p	Amount of pollution caused by transporting product p from r to c	erc_{rc}^p
Energy use for destroy one unit p in e	ne_e^p	Amount of pollution caused by transporting product p from c to k	eck_{ck}^p
Energy use for transport unit sp from s to m	nsm_{sm}^{sp}	Amount of pollution caused by transporting product p from k to m	ekm_{km}^p
Energy use for transport unit p from m to d	nmd_{md}^p	Amount of pollution caused by transporting product p from k to sm	$eksm_{ksm}^p$
Energy use for transport unit p from d to r	ndr_{dr}^p	Amount of pollution caused by transporting product p from k to e	eke_{ke}^p
Energy use for transport unit p from r to c	nrc_{rc}^p	Capacity of main supplier s for sp	$caps_s^p$
Energy use for transport unit p from c to k	nck_{ck}^p	Capacity of manufacturer m for p	$capm_m^p$

Energy use for transport unit p from k to sm	$nksm_{ksm}^{p}$	Capacity of distribution center d for p	$capd_{d}^{p}$
Energy use for transport unit p from k to e	nke_{ke}^{p}	Capacity of retailer r for p	$capr_{r}^{p}$
Energy use for transport unit p from k to m	nkm_{km}^{p}	Capacity of collection center c for p	$capc_{c}^{p}$
The probability of occurrence of sc scenario	pr^{sc}	Capacity of repair center k for p	$capk_{k}^{p}$
Percentage of products delivered to collection centers	βr^{p}	Capacity of disposal center e for p	$cape_{e}^{p}$
Amount of pollution caused by transporting product p from c to e	ece_{ce}^{p}	Salable percentage of product p in second customer	ak^{p}
Percentage of the transfer product from k to e	$beta2$	Percentage of the transfer product from k to e	ae^{p}
Percentage of the transfer product from c to k	$alfa$	Percentage of the transfer product from k to sm	$beta$
Cost allocation from d to r	cdr_{dr}	Cost allocation from m to d	cmd_{md}
Cost allocation from s to m	csm_{sm}	Cost allocation from c to k	cck_{ck}
Fix cost of installing backup supplier (l)	fcl_{l}	Capacity of backup supplier l for sp	$capl_{l}^{sp}$
Percentage that main supplier can cover raw materials under each scenario	$delts_{s}^{sc}$	Percentage that backup supplier can cover raw materials under each scenario	$delts_{l}^{sc}$
Disruption to the main supplier	gs_{s}^{sc}	Amount of product p transfer by each manufacturer under each scenario	pp_{m}^{sc}
Energy use for backup supplier l to produce sp	nsl_{l}^{sp}	Water use to provide sp by l	wsl_{l}^{sp}
Energy use for transport unit sp from l to m	$nsml_{lm}^{sp}$	Amount of pollution provided unit sp by l	esl_{l}^{sp}
Amount of local employment due to construction of a backup supplier l	oel_{l}^{sp}	Amount of pollution caused by transporting product p from l to m	$esml_{lm}^{sp}$
Cost allocation from l to m	$vsml_{lm}$	Variable cost of providing the production requirements of sp by l	$vcsl_{l}^{sp}$
Cost allocation from k to m	$vkm1_{km}$	Cost allocation from k to sm	$vksm1_{ksm}$
Variable cost of transporting unit p from m to d	$vmd1_{md}$	Variable cost of transporting unit p from k to e	$vce1_{ce}^{p}$
Variable cost of transporting unit sp from l to m	$vsmll_{lm}^{sp}$	Variable cost of transporting unit p from k to sm	$vksm_{ksm}^{p}$
Manufacturing cost per product unit p	$costp$	Energy use for transport unit p from c to e	nce_{ce}^{p}
budget available for facility establishment	BD		

Decision Variables

Description	**Decision variable**	**Description**	**Decision variable**
If a backup supplier l is open 1, otherwise 0	xl_{l}	If product p is transport from k to m under scenario sc 1, otherwise 0	ykm_{km}^{psc}
If a main supplier s is open 1, otherwise 0	xs_{s}	If product p is transport from k to sm under scenario sc 1, otherwise 0	$yksm_{ksm}^{psc}$
If a manufacturer m is open 1, otherwise 0	xm_{m}	If product p is transport from k to e under scenario sc 1, otherwise 0	yke_{ke}^{psc}
If a distribution center d is open 1, otherwise 0	xd_{d}	Amount of transportation raw material sp from s to m in scenario sc	qsm_{sm}^{spsc}
If a retailer r is open 1, otherwise 0	xr_{r}	Amount of transportation raw material sp from l to m in scenario sc	$qsml_{lm}^{spsc}$

If a collection center c is open 1, otherwise 0	xc_c	Amount of transportation product p from d to r in scenario sc	qr_{dr}^{psc}
If a repairing center k is open 1, otherwise 0	xk_k	Amount of transportation product p from r to c in scenario sc	qc_{rc}^{psc}
If a disposal center e is open 1, otherwise 0	xe_e	Amount of transportation product p from c to k in scenario sc	qk_{ck}^{psc}
If raw material sp is transport from s to m under scenario sc 1, otherwise 0	ysm_{sm}^{spsc}	Amount of transportation product p from k to e in scenario sc	qke_{ke}^{psc}
If product p is transport from m to d under scenario sc 1, otherwise 0	ymd_{md}^{psc}	Amount of transportation product p from k to m in scenario sc	qkm_{km}^{psc}
If product p is transport from d to r under scenario sc 1, otherwise 0	ydr_{dr}^{psc}	Amount of transportation product p from m to d in scenario sc	qmd_{md}^{psc}
If product p is transport from r to c under scenario sc 1, otherwise 0	yrc_{rc}^{psc}	If raw material sp is transport from l to m under scenario sc 1, otherwise 0	$ysml_{lm}^{spsc}$
If product p is transport from c to k under scenario sc 1, otherwise 0	yck_{ck}^{psc}	Amount of transportation product p from c to e in scenario sc	qce_{ce}^{psc}
The amount of budget obtained from loans b	LB_b		

Covariates

Description	**Covariate variable**	**Description**	**Covariate variable**
Total cost of the network under sc scenario	$TCost^{st}$	Fix cost	$FixCost$
Variable cost under sc scenario	$VariableCost^{st}$	Inventory cos under scenario sc	$InventoryCost^{st}$
Energy use under sc scenario	Eng^{st}	Pollution under sc scenario	Ems^{st}
Water use under sc scenario	Wtr^{st}	Extent of the network's ability to fulfill social responsibilities	$SRe\ s$

The first target function: cost minimization

$$\min\ TCOST^{sc} = FixedCost + Variable\ Cost^{sc} + Inventory\ Cost^{sc} \qquad \forall sc \tag{3.1}$$

$$\begin{aligned}
FixedCost = {} & \sum_{s} fcs_s \times xs_s + \sum_{s} fcl_l \times xl_l + \sum_{m} fcm_m \times xm_m + \sum_{d} fcd_d \times xd_d + \sum_{r} fcr_r \times xr_r + \sum_{c} fcc_c \times xc_c \\
& + \sum_{k} fck_k \times xk_k + \sum_{e} fce_e \times xe_e + \sum_{p}\sum_{sc}\sum_{d}\sum_{r} ydr_{dr}^{psc} \times cdr_{dr} + \sum_{p}\sum_{sc}\sum_{m}\sum_{d} ymd_{md}^{psc} \times cmd_{md} \\
& + \sum_{sp}\sum_{sc}\sum_{s}\sum_{m} ysm_{sm}^{spsc} \times csm_{sm} + \sum_{p}\sum_{sc}\sum_{c}\sum_{k} yck_{ck}^{psc} \times cck_{ck} + \sum_{sp}\sum_{sc}\sum_{l}\sum_{m} ysml_{lm}^{spsc} \times vsml_{lm} \\
& + \sum_{p}\sum_{sc}\sum_{k}\sum_{sm} yksm_{ksm}^{psc} \times vksm1_{ksm} + \sum_{p}\sum_{sc}\sum_{k}\sum_{m} ykm_{km}^{psc} \times vkm1_{km}
\end{aligned}$$

$$\begin{aligned}
Variable\ Cost^{sc} = {} & \sum_{sp}\sum_{s}\sum_{m} vcs_s^{sp} \times qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m} vcsl_l^{sp} \times qsml_{lm}^{spsc} + \sum_{p}\sum_{m}\sum_{d} vcm_m^{p} \times qd_{md}^{psc} \\
& + \sum_{m}\sum_{p} pp_m^{sc} \times costp_p + \sum_{sp}\sum_{s}\sum_{m} vsm_{sm}^{sp} \times qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m} vsml2_{lm}^{sp} \times qsml_{lm}^{spsc} \\
& + \sum_{p}\sum_{sc}\sum_{m}\sum_{d} ymd_{md}^{psc} \times cmd_{md} + \sum_{sp}\sum_{sc}\sum_{s}\sum_{m} ysm_{sm}^{spsc} \times csm_{sm} \\
& + \sum_{p}\sum_{d}\sum_{r} vdr_{dr}^{p} \times qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c} vrc_{rc}^{p} \times qc_{rc}^{psc} + \sum_{p}\sum_{c}\sum_{k} vck_{ck}^{p} \times qk_{ck}^{psc} \\
& + \sum_{p}\sum_{k}\sum_{e} vke_{ke}^{p} \times qke_{ke}^{psc} + \sum_{p}\sum_{k}\sum_{e} vkm_{km}^{p} \times qkm_{km}^{psc} + \sum_{p}\sum_{k}\sum_{sm} vksm_{ksm}^{p} \times qksm_{ksm}^{psc} \\
& + \sum_{p}\sum_{m}\sum_{d} qmd_{md}^{psc} \times vmd1_{md}^{p} + \sum_{p}\sum_{c}\sum_{e} qce_{ce}^{psc} \times vcel_{ce}^{p} + \sum_{p}\sum_{c}\sum_{k} vck_{k}^{p} \times qk_{ck}^{psc}
\end{aligned}$$

$$Inventory\ Cost^{sc} = \sum_{p}\sum_{m}\sum_{d} vcd_d^p \times qd_{md}^{psc} + \sum_{p}\sum_{d}\sum_{r} vcr_r^p \times qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c} vcc_c^p \times qsm_{rc}^{psc}$$

Equation (3.1) shows the first target function minimizing network costs and including fixed costs, variable costs, and inventory costs. Fixed costs include construction costs, allocation costs, variable costs including the costs of the required supplies for the production of raw materials by the main and backup suppliers, production and repair costs, and costs of shipping between facilities. Inventory costs include the costs of maintaining products in distribution centers, retail centers, and repair centers.

The second target function: minimization of harmful environmental effects

$$\min\ TEnv^{sc} = Eng^{sc} + Ems^{sc} + Wtr^{sc}; \qquad \forall sc \tag{3.2}$$

$$\begin{aligned} Eng^{sc} = {} & \sum_{sp}\sum_{s}\sum_{m}(ns_s^{sp} + nsm_{sm}^{sp})qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m}(nsl_l^{sp} + nsml_{lm}^{sp})qsml_{lm}^{spsc} + \sum_{p}\sum_{m}\sum_{d}(nm_m^p + nmd_{md}^p)qmd_{md}^{psc} \\ & + \sum_{p}\sum_{d}\sum_{r}(nd_d^p + ndr_{dr}^p)qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c}(nr_r^p + nrc_{rc}^p)qc_{rc}^{psc} + \sum_{p}\sum_{c}\sum_{k}(nc_c^p + nck_{ck}^p)qk_{ck}^{psc} \\ & + \sum_{p}\sum_{e}\sum_{k}(ne_e^p + nke_{ke}^p)qke_{ke}^{psc} + \sum_{p}\sum_{m}\sum_{k}(nm_m^p + nkm_{km}^p)qkm_{km}^{psc} + \sum_{p}\sum_{sm}\sum_{k}(nk_k^p + nksm_{ksm}^p)qksm_{ksm}^{psc} \\ & + \sum_{p}\sum_{c}\sum_{e}(ne_e^p + nce_{ce}^p)qce_{ce}^{psc} \end{aligned}$$

$$\begin{aligned} Ems^{sc} = {} & \sum_{sp}\sum_{s}\sum_{m}(es_s^{sp} + esm_{sm}^{sp})qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m}(esl_l^{sp} + eslm_{lm}^{sp})qsml_{lm}^{spsc} + \sum_{p}\sum_{m}\sum_{d}(em_m^p + emd_{md}^p)qd_{md}^{psc} \\ & + \sum_{p}\sum_{d}\sum_{r}(ed_d^p + edr_{dr}^p)qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c}(er_r^p + erc_{rc}^p)qc_{rc}^{psc} + \sum_{p}\sum_{c}\sum_{k}(ec_c^p + eck_{ck}^p)qk_{ck}^{psc} \\ & + \sum_{p}\sum_{e}\sum_{k}(ee_e^p + eke_{ke}^p)qke_{ke}^{psc} + \sum_{p}\sum_{m}\sum_{k}(em_m^p + ekm_{km}^p)qkm_{km}^{psc} + \sum_{p}\sum_{sm}\sum_{k}(ek_k^p + eksm_{ksm}^p)qksm_{ksm}^{psc} \\ & + \sum_{p}\sum_{c}\sum_{e}(ee_e^p + ece_{ce}^p)qce_{ce}^{psc} \end{aligned}$$

$$\begin{aligned} Wtr^{sc} = {} & \sum_{sp}\sum_{s}\sum_{m} ws_s^{sp} qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m} ws_l^{sp} qsml_{lm}^{spsc} + \sum_{p}\sum_{m}\sum_{d} wm_m^p qd_{md}^{psc} + \sum_{p}\sum_{d}\sum_{r} wd_d^p qr_{dr}^{psc} \\ & + \sum_{p}\sum_{r}\sum_{c} wr_r^p qc_{rc}^{psc} + \sum_{p}\sum_{c}\sum_{k} wc_c^p qk_{ck}^{psc} + \sum_{p}\sum_{k}\sum_{c} wk_k^p qk_{ck}^{psc} + \sum_{p}\sum_{k}\sum_{e} we_e^p qke_{ke}^{psc} + \sum_{p}\sum_{c}\sum_{e} we_e^p qce_{ce}^{psc} \end{aligned}$$

Equation (3.2) shows the second target function minimizing harmful environmental effects on the proposed network and including the amount of carbon dioxide (CO_2) produced and the amount of energy and water consumption in the supply chain. The energy consumed includes the energy needed for the supply and production of raw materials by the main suppliers and backup suppliers, product production, product maintenance in distribution, retail, collection and inspection, repair, and disposal centers, and energy needed for transportation between facilities. CO_2 produced includes CO_2 from the production and supply of raw materials by main and backup suppliers, product production, product maintenance in distribution, retail, collection and inspections, repair and disposal centers, as well as carbon dioxide caused by transportation between the facilities. The water consumed in the supply chain includes the water consumed for the supply and production of raw materials by main and backup suppliers, product production, product distribution by distributors and retailers, collection and inspection, repair, and disposal.

The third target function: Social responsibility

$$\begin{aligned} \max\ s\ Res = {} & \sum_{s}\sum_{p} os_s^p xs_s + \sum_{l}\sum_{sp} oel_l^{sp} xl_l + \sum_{m}\sum_{p} om_m^p xm_m + \sum_{m}\sum_{p} od_d^p xd_d \\ & + \sum_{r}\sum_{p} orr_r^p xr_r + \sum_{k}\sum_{p} ok_k^p xc_c + \sum_{k}\sum_{p} oe_e^p xe_e \end{aligned} \tag{3.3}$$

equation (3.3) shows the third target function maximizing the number of jobs created by the construction of the facility.

Constraints

$$hh_{sp} \times pp_{m}^{sp} = \sum_{s} (qsm_{sm}^{spsc}/(1 - delts_{s}^{sc})) + \sum_{l} (qsml_{m}^{spsc}/(1 - deltl_{l}^{sc})); \quad \forall m.sc.sp \tag{3.4}$$

$$pp_{m}^{sc} = \sum_{p} \sum_{d} qmd_{md}^{psc}; \quad \forall m.sc \tag{3.5}$$

$$\sum_{r} qr_{dr}^{psc} \leq \sum_{m} qmd_{md}^{psc}; \quad \forall d.p.sc \tag{3.6}$$

$$\sum_{c} qc_{rc}^{psc} \leq \sum_{d} qr_{dr}^{psc}; \quad \forall r.p.sc \tag{3.7}$$

$$\sum_{c} qc_{rc}^{psc} = \beta r^{p} \sum_{d} qr_{dr}^{psc}; \quad \forall r.p.sc \tag{3.8}$$

$$(1 - \alpha) \sum_{r} qc_{rc}^{psc} = \sum_{e} qce_{ce}^{psc}; \quad \forall c.p.sc \tag{3.9}$$

$$\sum_{k} qk_{ck}^{psc} = \alpha \sum_{r} qc_{rc}^{psc}; \quad \forall c.p.sc \tag{3.10}$$

$$\sum_{sm} qksm_{ksm}^{psc} = \beta \sum_{c} qk_{ck}^{psc}; \quad \forall k.p.sc \tag{3.11}$$

$$\sum_{m} qkm_{km}^{psc} = (1 - (\beta + \gamma)) \sum_{c} qk_{ck}^{psc}; \quad \forall r.p.sc \tag{3.12}$$

$$\sum_{e} qke_{ke}^{psc} = \gamma \sum_{c} qk_{ck}^{psc}; \quad \forall k.p.sc \tag{3.13}$$

$$\sum_{sc} \sum_{d} qr_{dr}^{psc} \geq d_{r}^{p}; \quad \forall r.p \tag{3.14}$$

$$ydr_{dr}^{psc} \leq xd_{d}; \quad \forall r.d.p.sc \tag{3.15}$$

$$ymd_{md}^{psc} \leq xm_{m}; \quad \forall d.m.p.sc \tag{3.16}$$

$$ykm_{km}^{psc} \leq xm_{m}; \quad \forall p.sc.k.m \tag{3.17}$$

$$ykm_{km}^{psc} \leq xk_{k}; \quad \forall p.sc.k.m \tag{3.18}$$

$$ykm_{km}^{psc} \leq xk_{k}; \quad \forall p.sc.k.sm \tag{3.19}$$

$$ysm_{sm}^{spsc} \leq xs_{s}; \quad \forall s.m.p.sc \tag{3.20}$$

$$ysml_{lm}^{spsc} \leq xl_{l}; \quad \forall l.m.p.sc \tag{3.21}$$

$$ysm_{sm}^{spsc} \leq xm_{m}; \quad \forall s.m.p.sc \tag{3.22}$$

$$qc_{rc}^{psc} \leq xc_{c} \; capr_{r}^{p}; \quad \forall r.p.sc.c \tag{3.23}$$

$$qk_{ck}^{psc} \leq xk_{k} \; capk_{k}^{p}; \quad \forall c.k.p.sc \tag{3.24}$$

$$\sum_{k} qke_{ke}^{psc} \leq cape_{e}^{p}; \quad \forall e.p.sc \tag{3.25}$$

$$qmd_{md}^{psc} \leq xd_{d} \; capd_{d}^{p}; \quad \forall m.d.p.sc \tag{3.26}$$

$$\sum_{d} qmd_{md}^{psc} \leq capm_{m}^{p} \times xm_{m}; \quad \forall s.m.p.sc \tag{3.27}$$

$$qsm_{sm}^{spsc} \leq BIGM \times ysm_{sm}^{spsc}; \quad \forall s.sp.sc.m \tag{3.28}$$

$$qsml_{lm}^{spsc} \leq BIGM \times ysml_{lm}^{spsc}; \quad \forall l.sp.sc.m \tag{3.29}$$

$$qmd_{md}^{psc} \leq BIGM \times ymd_{md}^{psc}; \quad \forall m.d.p.sc \tag{3.30}$$

$$qr_{dr}^{psc} \leq BIGM \times ydr_{dr}^{psc}; \quad \forall r.d.p.sc \tag{3.31}$$

$$qk_{ck}^{psc} \leq BIGM \times yck_{ck}^{psc}; \quad \forall c.k.p.sc \tag{3.32}$$

$$qkm_{km}^{psc} \leq BIGM \times ykm_{km}^{psc}; \quad \forall p.sc.k.m \tag{3.33}$$

$$qksm_{ksm}^{psc} \leq BIGM \times yksm_{ksm}^{psc}; \quad \forall m.k.p.sc \tag{3.34}$$

$$\sum_{s} ysm_{sm}^{spsc} \leq 1; \quad \forall sp.sc.m \tag{3.35}$$

$$\sum_{l} ysml_{lm}^{spsc} \leq 1; \quad \forall sp.sc.m \tag{3.36}$$

$$\sum_{m} ymd_{md}^{psc} \leq 1; \quad \forall d.p.sc \tag{3.37}$$

$$\sum_{d} ydr_{dr}^{psc} \leq 1; \quad \forall r.p.sc \tag{3.38}$$

$$\sum_{k} ykm_{km}^{psc} \leq 1; \quad \forall p.sc.m \tag{3.39}$$

$$\sum_{k} yksm_{ksm}^{psc} \leq 1; \quad \forall p.sc.sm \tag{3.40}$$

$$qke_{ke}^{psc} \leq BIGM \times xe_e; \quad \forall e.k.p.sc \tag{3.41}$$

$$qce_{ce}^{psc} \leq BIGM \times xe_e; \quad \forall e.k.p.sc \tag{3.42}$$

$$\sum_{sp}\sum_{m} qsm_{sm}^{spsc}/(1 - delts_s^{sc}) \leq (1 - GS_s^{sc}) \times caps_s \times xs_s; \quad \forall s.sc \tag{3.43}$$

$$\sum_{sp}\sum_{m} qsml_{lm}^{spsc}/(1 - deltl_l^{sc}) \leq capl_l \times xl_l; \quad \forall l.sc \tag{3.44}$$

$$\begin{aligned}\sum_{b} LB_b + BD \geq \sum_{s} fcs_s \times xs_s + \sum_{s} fcl_l \times xl_l + \sum_{m} fcm_m \times xm_m + \sum_{d} fcd_d \times xd_d \\ + \sum_{r} fcr_r \times xr_r + \sum_{c} fcc_c \times xc_c + \sum_{k} fck_k \times xk_k + \sum_{e} fce_e \times xe_e\end{aligned} \tag{3.45}$$

$$xl_l.xs_s.xm_m.xd_d.xr_r.xc_c.xk_k.xe_e.ysm_{sm}^{spsc}.ymd_{md}^{psc}.ydr_{dr}^{psc}.yrc_{rc}^{psc}.yck_{ck}^{psc}.ysml_{lm}^{spsc}.ykm_{km}^{psc}.yksm_{ksm}^{psc}.yke_{ke}^{psc} \in \{0.1\} \tag{3.46}$$

$$qce_{ce}^{psc}.qsm_{sm}^{spsc}.qd_{md}^{psc}.qr_{dr}^{psc}.qc_{rc}^{psc}.qk_{ck}^{psc}.qke_{ke}^{psc}.qkm_{km}^{psc}.qksm_{ksm}^{psc}.qmd_{md}^{psc}.qsml_{lm}^{spsc} \geq 0.Int \tag{3.47}$$

Constraint (3.4) ensures the balance between the amount of raw material needed by the manufacturers for production and the extent of raw material provided by suppliers. Constraint (3.5) ensures the balance between the amount of produced products and the amount of products sent to the distributors by manufacturers. Constraint (3.6) ensures that the amount of product sent to retailers by the distributor cannot exceed the amount of his input product. Constraint (3.7) ensures that the amount of product sent to customer areas and collection centers by the retailers cannot exceed their amount of input product. Constraint (3.8) shows the amount of products sent to the collection and inspection centers in the supply chain by retailers. Constraint (3.9) shows the amount of unrepairable products from returned products transferred from collection and inspection centers to disposal centers. Constraint (3.10) shows the amount of returned products sent from the collection and inspection centers to repair centers. Constraint (3.11) shows the amount of products repaired in the repair centers and shipped to the second market. Constraint (3.12) shows the amount of high-quality repaired products shipped from the repair centers to manufacturers for recycle. Constraint (3.13) shows the amount of unrepairable products shipped from the repair centers to disposal centers. Constraint (3.14) ensures that customer demand is fully fulfilled. Constraints (3.15) to (3.22) guarantee that sending from any facility depends on constructing it. Constraints (3.23) to (3.27) show that the entry of products to the facilities or exit of the product from them should not exceed their capacity. Constraints (3.28) to (3.40) relate to the allocation of facilities. Constraints (3.41) and (3.42) are related to the location of the disposal centers. Constraints (3.43) and (3.44) show the amount of raw materials prepared by the main and backup suppliers in different scenarios. The limitation presented in (3.45) guarantees that the total cost of establishing the facility does not exceed the sum of the initial budget and received loans. Constraints (3.46) and (3.47) are related to the binary, positive, and integer nature of the decision variables.

The Robust Counterpart of the Proposed Model

Due to the uncertainty in market demand and insufficient information about cost parameters, demand and cost parameters are considered as trapezoidal fuzzy numbers $\tilde{\xi} = (\xi_1.\xi_2.\xi_3.\xi_4)$; For instance, for the demand (d_r^p) we have $(d1_r^p.d2_r^p.d3_r^p.d4_r^p)$ whose definitive equivalent is calculated as follows based on [13]:

$$EV[\tilde{\xi}] = \frac{\xi_1.\xi_2.\xi_3.\xi_4}{4} \tag{3.48}$$

In addition, to determine fuzzy numbers, the third fuzzy number is equal to the definitive state and the numbers of first, second, and fourth fuzzy numbers are valued as:

$$\xi_1 = 0.6 \times \xi_3; \xi_2 = 0.8 \times \xi_3; \xi_3 = \xi; \xi_4 = 1.4 \times \xi_3 \tag{3.49}$$

Pishvaee et al.'s robust possibilistic programming (RPP) model was used to eliminate uncertainties in the proposed model. According to this method [27], since the first purpose of the model, i.e. the costs, is uncertain, its definitive state is as below:

$$\begin{aligned} \min\ TCOST^{sc} = {} & FixedCost + Variable\ Cost^{sc} + Inventory\ Cost^{sc} + \pi \times (d4_r^p - (\alpha \times d4_r^p + (1-\alpha) \times d3_r^p) \\ & + \varphi \times (\beta \times GS1_s^{sc} + (1-\beta) \times GS2_s^{sc}) - GS1_s^{sc}) \qquad \forall sc \end{aligned} \tag{3.50}$$

$$\begin{aligned} FixedCost = {} & \sum_s \frac{fcs1_s + fcs2_s + fcs3_s + fcs4_s}{4} \times xs_s + \sum_l \frac{fcl1_l + fcl2_l + fcl3_l + fcl4_l}{4} \times xl_l \\ & + \sum_m \frac{fcm1_m + fcm2_m + fcm3_m + fcm4_m}{4} \times xm_m + \sum_d \frac{fcd1_d + fcd2_d + fcd3_d + fcd4_d}{4} \times xd_d \\ & + \sum_r \frac{fcr1_r + fcr2_r + fcr3_r + fcr4_r}{4} \times xr_r + \sum_c \frac{fcc1_c + fcc2_c + fcc3_c + fcc4_c}{4} \times xc_c \\ & + \sum_k \frac{fck1_k + fck2_k + fck3_k + fck4_k}{4} \times xk_k + \sum_e \frac{fce1_e + fce2_e + fce3_e + fce4_e}{4} \times xe_e \\ & + \sum_p \sum_{sc} \sum_d \sum_r ydr_{dr}^{psc} \times \frac{cdr1_{dr} + cdr2_{dr} + cdr3_{dr} + cdr4_{dr}}{4} \\ & + \sum_p \sum_{sc} \sum_m \sum_d ymd_{md}^{psc} \times \frac{cmd1_{md} + cmd2_{md} + cmd3_{md} + cmd4_{md}}{4} \\ & + \sum_{sp} \sum_{sc} \sum_s \sum_m ysm_{sm}^{spsc} \times \frac{csm1_{sm} + csm2_{sm} + csm3_{sm} + csm4_{sm}}{4} \\ & + \sum_p \sum_{sc} \sum_c \sum_k yck_{ck}^{psc} \times \frac{cck1_{ck} + cck2_{ck} + cck3_{ck} + cck4_{ck}}{4} \\ & + \sum_{sp} \sum_{sc} \sum_l \sum_m ysml_{lm}^{spsc} \times \frac{vsml1_{lm} + vsml2_{lm} + vsml3_{lm} + vsml4_{lm}}{4} \\ & + \sum_p \sum_{sc} \sum_k \sum_{sm} yksm_{ksm}^{psc} \times \frac{vksm1_{ksm} + vksm2_{ksm} + vksm3_{ksm} + vksm4_{ksm}}{4} \\ & + \sum_p \sum_{sc} \sum_k \sum_m ykm_{km}^{psc} \times \frac{vkm11_{km} + vkm12_{km} + vkm13_{km} + vkm14_{km}}{4} \\ & + \sigma \times (FixedCostParameters(4) \times Variables) \end{aligned}$$

$$\begin{aligned} Variable\ Cost^{sc} = {} & \sum_{sp} \sum_s \sum_m \frac{vcs1_s^{sp} + vcs2_s^{sp} + vcs3_s^{sp} + vcs4_s^{sp}}{4} \times qsm_{sm}^{spsc} \\ & + \sum_{sp} \sum_l \sum_m \frac{vcsl1_l^{sp} + vcsl2_l^{sp} + vcsl3_l^{sp} + vcsl4_l^{sp}}{4} \times qsml_{lm}^{spsc} \\ & + \sum_p \sum_m \sum_d \frac{vcm1_m^p + vcm2_m^p + vcm3_m^p + vcm4_m^p}{4} \times qd_{md}^{psc} \\ & + \sum_m \sum_p pp_m^{sc} \times \frac{cost1_p + cost2_p + cost3_p + cost4_p}{4} \end{aligned}$$

$$
\begin{aligned}
&+\sum_{sp}\sum_{s}\sum_{m}\frac{vsm1_{sm}^{sp}+vsm2_{sm}^{sp}+vsm3_{sm}^{sp}+vsm4_{sm}^{sp}}{4}\times qsm_{sm}^{spsc}\\
&+\sum_{sp}\sum_{l}\sum_{m}\frac{vsmll1_{lm}^{sp}+vsmll2_{lm}^{sp}+vsmll3_{lm}^{sp}+vsmll4_{lm}^{sp}}{4}\times qsml_{lm}^{spsc}\\
&+\sum_{p}\sum_{d}\sum_{r}\frac{vdr1_{dr}^{p}+vdr2_{dr}^{p}+vdr3_{dr}^{p}+vdr4_{dr}^{p}}{4}\times qr_{dr}^{psc}\\
&+\sum_{p}\sum_{r}\sum_{c}\frac{vrc1_{rc}^{p}+vrc2_{rc}^{p}+vrc3_{rc}^{p}+vrc4_{rc}^{p}}{4}\times qc_{rc}^{psc}\\
&+\sum_{p}\sum_{c}\sum_{k}\frac{vck1_{ck}^{p}+vck2_{ck}^{p}+vck3_{ck}^{p}+vck4_{ck}^{p}}{4}\times qk_{ck}^{psc}\\
&+\sum_{p}\sum_{k}\sum_{e}\frac{vke1_{ke}^{p}+vke2_{ke}^{p}+vke3_{ke}^{p}+vke4_{ke}^{p}}{4}\times qke_{ke}^{psc}\\
&+\sum_{p}\sum_{k}\sum_{e}\frac{vkm1_{km}^{p}+vkm2_{km}^{p}+vkm3_{km}^{p}+vkm4_{km}^{p}}{4}\times qkm_{km}^{psc}\\
&+\sum_{p}\sum_{k}\sum_{sm}\frac{vksm1_{ksm}^{p}+vksm2_{ksm}^{p}+vksm3_{ksm}^{p}+vksm4_{ksm}^{p}}{4}\times qksm_{ksm}^{psc}\\
&+\sum_{p}\sum_{m}\sum_{d}qmd_{md}^{psc}\times\frac{vmd1_{md}^{p}+vmd2_{md}^{p}+vmd3_{md}^{p}+vmd4_{md}^{p}}{4}\\
&+\sum_{p}\sum_{c}\sum_{e}qce_{ce}^{psc}\times\frac{vcel1_{ce}^{p}+vcel2_{ce}^{p}+vcel3_{ce}^{p}+vcel4_{ce}^{p}}{4}\\
&+\sum_{p}\sum_{c}\sum_{k}\frac{vck1_{k}^{p}+vck2_{k}^{p}+vck3_{k}^{p}+vck4_{k}^{p}}{4}\times qk_{ck}^{psc}+\sigma\times(Variable\ CostParameters(4)\times Variables)
\end{aligned}
$$

$$
\begin{aligned}
Inventory\ Cost^{sc}=&\sum_{p}\sum_{m}\sum_{d}\frac{vcd1_{d}^{p}+vcd2_{d}^{p}+vcd3_{d}^{p}+vcd4_{d}^{p}}{4}\times qd_{md}^{psc}+\sum_{p}\sum_{d}\sum_{r}\frac{vcr1_{r}^{p}+vcr2_{r}^{p}+vcr3_{r}^{p}+vcr4_{r}^{p}}{4}\times qr_{dr}^{psc}\\
&+\sum_{p}\sum_{r}\sum_{c}\frac{vcc1_{c}^{p}+vcc2_{c}^{p}+vcc3_{c}^{p}+vcc4_{c}^{p}}{4}\times qsm_{rc}^{psc}+\sigma\times(InventoryCostsParameters(4)\times Variables)
\end{aligned}
$$

Moreover, Constraints (3.14), (3.43) and (3.45) are examined under uncertainty, the definitive equivalent of which is ((3.51), (3.53) and (**??**)):

$$\sum_{sc}\sum_{d}qr_{dr}^{psc}\geq\alpha\times d4_{r}^{p}+(1-\alpha)\times d3_{r}^{p};\quad\forall r.p \tag{3.51}$$

$$\sum_{sp}\sum_{m}qsm_{sm}^{spsc}/(1-delts_{s}^{sc})\leq(1-(\beta\times GS1_{s}^{sc}+(1-\beta)\times GS2_{s}^{sc}))\times caps_{s}\times xs_{s};\quad\forall s.sc \tag{3.52}$$

$$
\begin{aligned}
&\sum_{s}[\mathfrak{r}1\times fcs4_{s}+(1-\mathfrak{r}1)\times fcs3_{s}]\times xs_{s}+\sum_{l}[\mathfrak{r}2\times fcl4_{l}+(1-\mathfrak{r}2)\times fcl3_{l}]\times xl_{l}\\
&+\sum_{m}[\mathfrak{r}3\times fcm4_{m}+(1-\mathfrak{r}3)\times fcm3_{m}]\times xm_{m}+\sum_{d}[\mathfrak{r}4\times fcd4_{d}+(1-\mathfrak{r}4)\times fcd3_{d}]\times xd_{d}\\
&+\sum_{r}[\mathfrak{r}5\times fcr4_{r}+(1-\mathfrak{r}5)\times fcr3_{r}]\times xr_{r}+\sum_{c}[\mathfrak{r}6\times fcc4_{c}+(1-\mathfrak{r}6)\times fcc3_{c}]\times xc_{c}\\
&+\sum_{k}[\mathfrak{r}7\times fck4_{k}+(1-\mathfrak{r}7)\times fck3_{k}]\times xk_{k}+\sum_{e}[\mathfrak{r}8\times fce_{4e}+(1-\mathfrak{r}8)\times fce3_{e}]\times xe_{e}\leq\sum_{b}LB_{b}+BD
\end{aligned}
\tag{3.53}
$$

4 Solving method

This study has used the AEC method, presented by [18] to solve the problem. This method is able to find efficient and non-convex Pareto curve. Also, the problem was simulated and solved using NSGA-II algorithm whose steps are shown in figure 2. This method is flexible. It provides a suitable answer with any type of objective function and

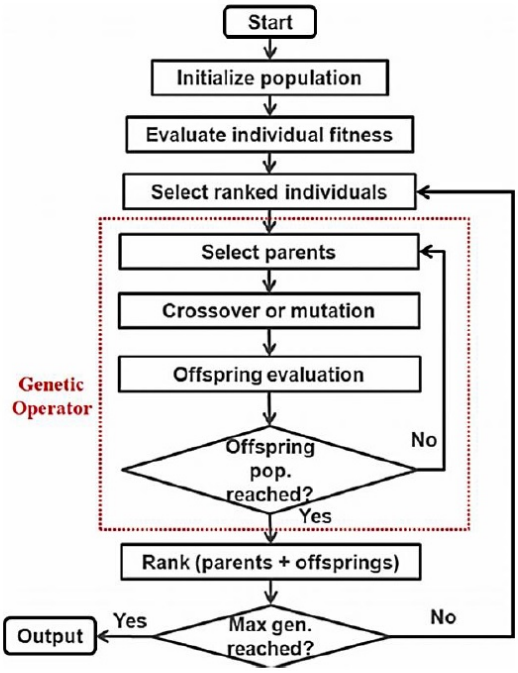


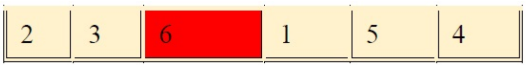
Figure 2: Flowchart of the proposed algorithm

restriction in the search space. Also, it has a multi-sided search and produces more answers in the Pareto front than other algorithms [4].

Since the main decisions of the presented model are of the location and allocation type, so in order to display the solution, a permutation structure was used to determine the location and allocation in order to simulate the model with the genetic algorithm, and because in this problem, several levels of the supply chain must be located and assigned, so a group of solutions was designed for each level of the chain, which is as follows:

- Assigning customers to distributors

  First, it should be determined which distributors will be established and which customers will be assigned to them. For this purpose, a random permutation is designed with the length of R+D-1. If it is assumed that the number of distributors is equal to 2 and the number of customers is equal to 5, this random permutation has a length equal to 6. The following vector is a random permutation for assigning a customer to a distributor.



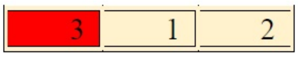
2	3	6	1	5	4

Figure 3: Random permutation for assigning customers to distributors

  As shown in the above vector, the number 6, which is greater than the number of customers, is the separator between the customers assigned to distributors 1 and 2. Based on the above vector, customers 2 and 3 are assigned to distributor 1 and customers 1, 5 and 4 are assigned to distributor 2. Since customers are assigned to both distributors, therefore these two distributors are built.

- Assigning distributors to manufacturers

  A random permutation vector of length M+D-1 is considered. If the number of producers is equal to 2 and the number of distributors is equal to 2, a permutation vector is as follows:



3	1	2

Figure 4: Random permutation for assigning distributors to manufacturers

In the above vector, the number 3 is the separator between the distributors assigned to producers 1 and 2. Based on the above vector, no distributor is assigned to producer 1, and as a result, producer 1 is not built, and distributors 1 and 2 are assigned to producer 2.

- Assigning manufacturers to backup suppliers

  A random permutation vector of length L+M-1 is considered. If the number of manufacturers and backup suppliers are equal to 2, a permutation vector is as follows:

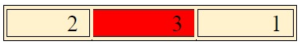


Figure 5: Random permutation for assigning manufacturers to backup suppliers

In the above vector, the number 3 is the separator between the manufacturers assigned to backup supplier 1 and 2. Based on the above vector, manufacturer 2 is assigned to backup supplier 1 and manufacturer 1 is assigned to backup supplier 2.

Based on the above examples, the other vectors to display the solution are as follows:

Table 1: Vector representation of the problem's answer

Assigning type	**size**
Assigning manufacturers to suppliers	S+M-1
Assigning collection centers to retailers	R+C-1
Assigning repairing centers to collection centers	K+C-1
Assigning disposal centers to repairing centers	E+K-1
Assigning disposal centers to collection centers	E+C-1
Assigning second customers to repairing centers	SM+K-1
Assigning manufacturers to repairing centers	M+K-1

According to this, the location of the facilities has been done and in order to create the flow of products, it is sufficient that the demand of customers should be satisfied in the last layer, which is done by using the relations of restrictions and the balance of the flow of products between the facilities.

Swap operator was used for mutation operation in genetic algorithm. In each vector, two numbers are selected from the answer and their places are exchanged with each other. For example, in the following chromosome, points 6 and 1 are exchanged with each other:

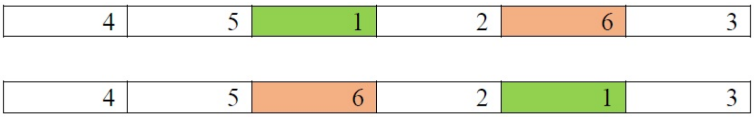


Figure 6: function of the mutation operator

A single point crossover was used to implement the crossover. In this method, a random point on each response vector is selected from both parents and new offspring are obtained by joining the opposite sides of each parent.

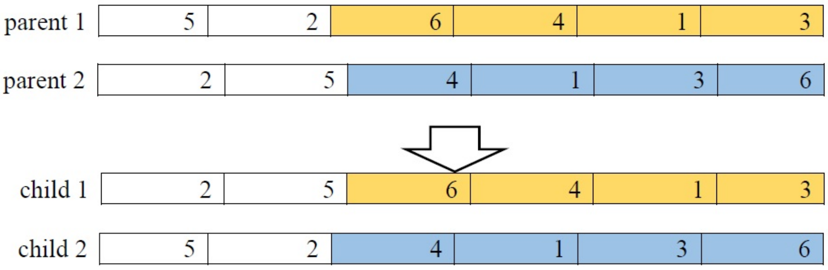


Figure 7: function of the crossover operator

Taguchi's method was used to adjust the parameters in the NSGA-II algorithm, the results of which are presented in Table 2.

Table 2: Algorithm parameters

mutation rate	**crossover rate**	**initial population size**	**maximum repetitions**
0.25	0.80	150	200

5 Numerical results

A problem in the form of table 3 was considered in order to evaluate the performance of the presented model:

Table 3: problem information

b	**sc**	**sp**	**p**	**sm**	**e**	**k**	**c**	**r**	**d**	**m**	**l**	**s**
2	2	2	2	2	2	2	2	5	2	2	2	3

The mathematical model resulting from the above problem is solved by CPLEX method in GAMS 24/3 and NSGA-II algorithm in MATLAB version 2018a software using random data in a notebook with Intel® Core^{TM} i5 processor and 4GbRAM memory and Microsoft Windows 10 Ultimate operating system.

The payoff matrix resulting from solving the model with the AEC method is as shown in Table 4:

Table 4: payoff matrix resulting from solving the model by AEC method

	F1	**F2**	**F3**
F1	61320.45	83641.34	97339.29
F2	48577.28	34117.26	33664.62
F3	54	108	108

Besides, the Pareto front resulting from solving the model using AEC method and NSGA-II algorithm is exhibited in Fig. 8:

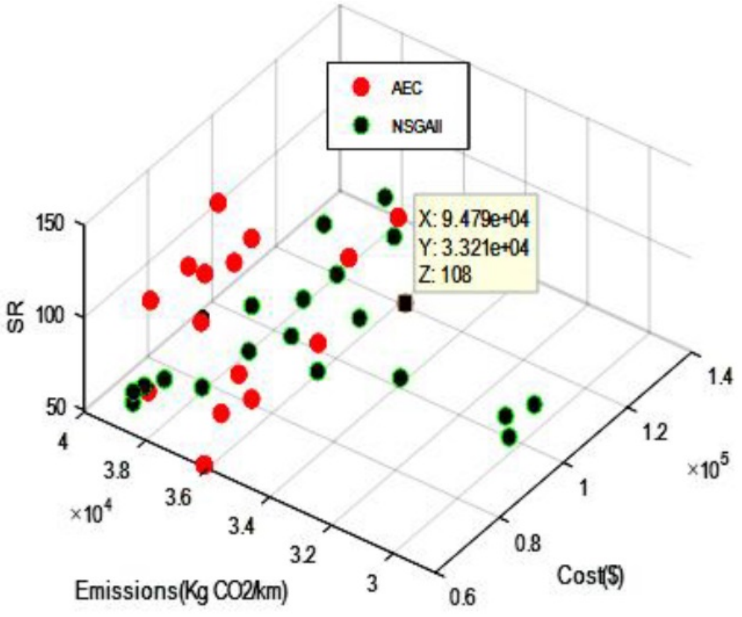


Figure 8: Pareto front created by AEC method and NSGA-II algorithm

Fig. 9 indicates the conflict between economic, environmental, and social responsibility goals. In other words, if the decision-makers focus on reducing environmental effects or increasing employment, more costs will be imposed to the supply chain.

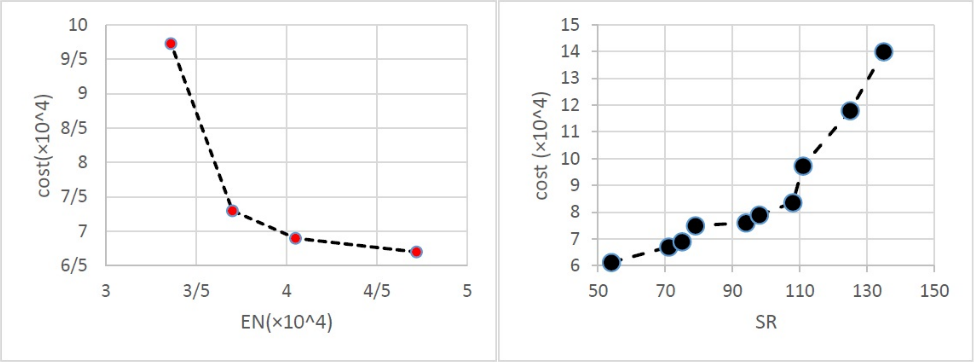


Figure 9: Conflict between economic-environmental-social responsibility goals

Consider the following parameters in order to analyze resilience:

$$caps_s^{sp} = 1500, \qquad delts_l^{sc} = 0.4, \qquad capl_l^{sp} = 1400, \qquad delts_s^{sc} = 0.90, \qquad gs_s^{sc} = 0.0$$

No backup supplier is constructed under non-disruptive conditions, and the required raw materials are supplied by three main suppliers. With 40% disruption, Model 1 considers a backup supplier to compensate for the disruption. The total amount of raw materials is 39 units shipped from the backup supplier and 238 units from the main supplier. With the increased disruption in the supply chain network, the network costs increase, since it has to get service from the backup suppliers and this increases the network costs. Fig. 10 shows the increase in costs in case of disruption of 40-80%.

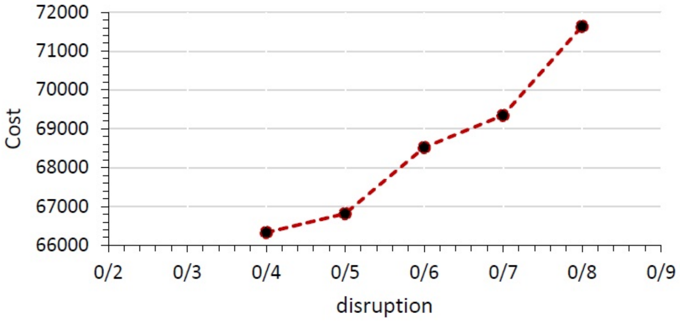


Figure 10: Relationship between disruption and cost

Figs. 11, 12, and 13 show the effect of decreasing the capacity of the main suppliers without causing disruption on the target functions:

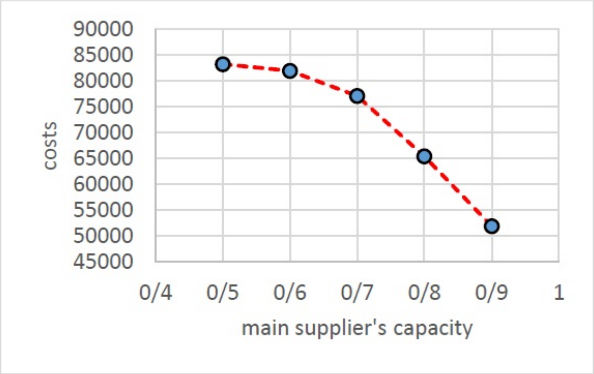


Figure 11: Relationship between the main supplier's capacity and costs

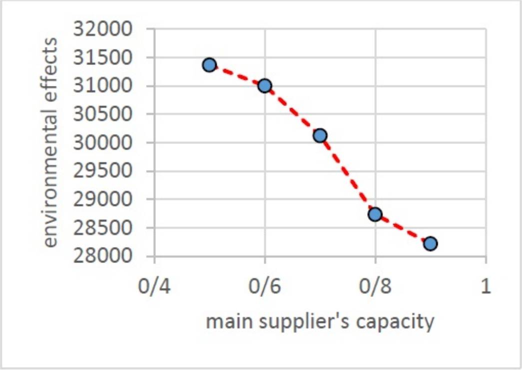


Figure 12: Relationship between the main supplier's capacity and environmental effects

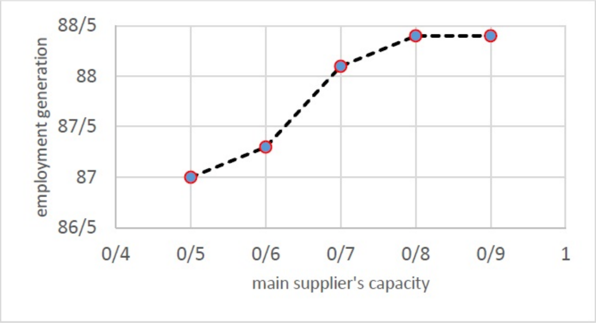


Figure 13: Relationship between the main supplier's capacity and employment generation

The model is implemented in the GAMS software environment by both methods in order to exhibit the efficiency of the mathematical model under the conditions of Robust Possibilistic Programming Approach. In RPP model, many tests must be done to find the appropriate level of confidence, a time-consuming process. Furthermore, there is no guarantee that the final selected confidence level is optimal. Besides, there are deviations in the constraints, including uncertainty. Consequently, this factor may cause the limitations to become impossible, i.e. a significant problem not considered in this method. Hence, to solve these problems, the RPP model is investigated, too.

The numerical example investigated in the current study is employed for both possibilistic programming and RPP methods. Uncertain parameters are considered as trapezoidal numbers.

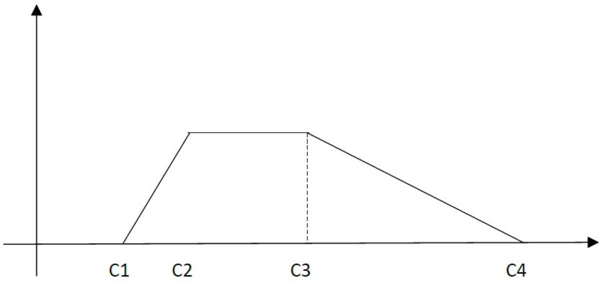


Figure 14: Fuzzy parameters with trapezoidal distribution

Based on Fig. 14, the C3 parameter is considered equal to the nominal value. The lower limit means that C1 is 40% lower than nominal value and C2 is 20% lower than nominal value, and finally C4 is 40% more that nominal value. For example, in accordance with what aforementioned, the demand parameter is described below:

$d3^{p}_{rsc} = Uniformint(50, 150)$

$d1^{p}_{rsc} = Round(d3^{p}_{rsc} - 0.4 * d3^{p}_{rsc})$

$d2^{p}_{rsc} = Round(d3^{p}_{rsc} - 0.2 * d3^{p}_{rsc})$

$$d4^{p}_{rsc} = Round(d3^{p}_{rsc} + 0.4 * d3^{p}_{rsc})$$

The same is applied for other uncertain parameters.

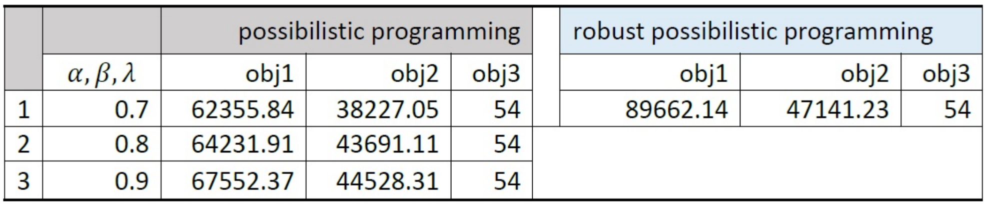
Now for validation of the proposed model, it is implemented in the RPP mode. To solve the three-objective possibilistic programming model, the second and third target functions are limited based on the table of payoff and limited to a specified value (the formula of the calculation of this limit for one iteration is presented) and finally the three-objective model was solved given the economic purpose, i.e. to minimize the cost of the total supply chain network. The possibilistic programming model is optimized by the reliability levels of 0.7, 0.8, and 0.9.

$$Epsilon2 = (MinFunction(obj2) + MaxFunction(obj2))/2\ RangFunction(obj2) \times uniform(-1, .8)/2$$

$$Epsilon3 = (MinFunction(obj3) + MaxFunction(obj3))/2 + RangFunction(obj3) \times uniform(-1, .8)/2$$

After executing the model in the above-mentioned output modes, the resulting output is visible in Table 5.

Table 5: Comparison of model results in possibilistic programming mode and robust possibilistic programming



		possibilistic programming			robust possibilistic programming		
	α, β, λ	obj1	obj2	obj3	obj1	obj2	obj3
1	0.7	62355.84	38227.05	54	89662.14	47141.23	54
2	0.8	64231.91	43691.11	54			
3	0.9	67552.37	44528.31	54			

According to the results, the increase in minimum scalability has led to an increase in costs due to the increase in demand and other parameters under uncertainty. The objective function of the two models in Figure 15 shows that the possibilistic programming at the confidence level of 0.9 is lower than the robust possibilistic programming with a penalty of 0.5.

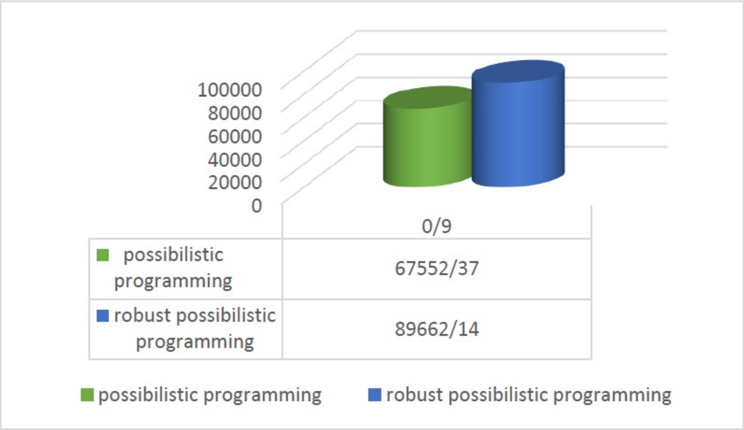


Figure 15: Comparison of possibilistic programming with gradability of 0.9 and robust possibilistic programming

6 Conclusion and recommendations

The researchers realized that in the supply chain, the integration of sustainability is a competitive advantage for the organization. On the other hand, the performance of the supply chain is greatly affected by disruptions. In the present paper, the issue of designing the closed-loop supply chain network under supply risk conditions was investigated considering sustainability criteria, aiming at minimizing the costs and harmful environmental effects in the chain and maximizing the created jobs according to decisions, given the location and the amount of flow between the facilities. Also, financial decisions such as capital management in the establishment of facilities were discussed so that the cost of establishing the facility should not exceed the target budget. The proposed model employed backup suppliers to make the supply chain resilient and reduce the suppliers' supply risk, and Pishvaee's robust possibilistic programming (RPP) model was used to eliminate the uncertainty. Then, the model was solved in deterministic and stable conditions using the method (AEC) and algorithm (NSGA-II) and the results were analyzed. The presented model determines in which of the potential centers the supply, production, distribution, retail, collection, repair, second market and disposal centers to be constructed, as well as how much the flow of products shipped between the facility would be. The results show that increased supply chain costs increase. In addition, reducing the main supplier's capacity may result in the increased environmental costs and effects as well as decreased number of created jobs. On the other hand, according to the results of the survey, increasing the available loan options can increase the level of services provided in the supply chain, and considering financial decisions and physical decisions integrated in the supply chain can improve the performance of the supply chain in terms of profitability and in terms of responding to customers' needs. Solving the possibilistic programming and PRR models shows that the value of the RPP model's target function at the highest confidence level is lower than the value of the target function of RPP model with the lowest level of fine. Also, the Pareto front obtained from solving the model using both AEC and NSGA-II methods shows that the solutions obtained from both methods are very close to each other.

The variety of different vehicles with different capacities can be considered in order to reduce transportation costs for future research. Also, various transportation operations including road, rail, air and sea can be taken into consideration due to logistic disturbances, which are in the form of parallel connections between facilities and enable alternative routes instead of the main route in case of problems for each route. Furthermore, the flow of products can be considered transversely and between similar facilities in order to increase resilience. It is suggested to pay attention to the risk of environmental factors such as exchange rate, inflation rate and their impact on investments, considering the economic conditions of the country. Another suggestion for future research is to solve the problem in larger dimensions using the proposed NSGA-II algorithm as well as other meta-heuristic algorithms.

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