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Presenting a multi-objective linear programming mathematical model of a resilient and sustainable supply chain with an emphasis on environmental factors with a robust optimization approach

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Abstract

Nowadays, the lack of natural resources and reserves of raw materials, besides the increased production costs and the problems with burying and destroying industrial waste, have attracted attention to product recovery and waste recycling in the framework of a closed-loop and sustainable supply chain, also able to create a competitive advantage. On the other hand, researches indicate that taking resilience approaches into account in supply chain design may protect buyers against disruptions such as natural, human, or technological disasters. The present paper presents a multi-objective mathematical model of a single-period, multi-product, and multi-level closed-loop supply chain, considering the dimensions of resilience and sustainability under conditions of uncertainty. Hence, a deterministic mixed integer linear programming model is initially presented; subsequently, to eliminate the uncertainty of the demand parameters and costs, its stochastic counterpart was presented based on Pishvaee's robust possibilistic programming (RPP) model. In order to solve the model, the Augmented Epsilon Constraint method was employed in the GAMS software environment. Ultimately, the model was solved and evaluated by a numerical example.

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

Designing the supply chain structure is aimed at determining the location, number, inventory of facilities, and the amount of flow sent between facilities, as well as reducing costs, etc. [33], in case of being correctly carried out, providing effective management of the chain in addition to creating a competitive advantage [2]. Today, competitive markets to increase the value level of the supply chain, have led companies to focus on environmental issues on a par with other important factors (cost, quality, level of service, etc.) [8] and a great attention has been paid to the use of sustainability criteria in the design of the supply chain structure [10], since focusing on the supply chain's internal efficiency is no longer sufficient to reach a competitive advantage, and in case of the integration of the sustainability concepts in the main parts of the organization's supply chain, the organization may reach a good position in the market [15], and moderate the negative burden on social, environmental, and competitive issues [17]. Sustainable supply chain management refers to a management process combining environmental considerations, social performance, and economic participation [29], besides creating a collection of appropriate capabilities for the organization in order to differentiate itself from competitors [15].

Natural disasters, acts of terrorism, and so on, increase supply chain's complexity, because the defect in one of the chain connections can defect the entire chain [30]; thus, designing a resilient supply chain is a response to these disturbances [25]. Supply chain resilience includes different strategies and measures to decline the risks and disruptions' destructive impacts on the supply chain [9]. Thus, recent relevant studies have considered resilient supply chain network design as an attractive research field [7]. A resilient supply chain is not low-cost; however, it should be noticed that a supply chain's competitive advantage is not only based on low costs, high quality, reduced delay time, and high level of service, but also overcoming critical conditions is considered as a competitive advantage, too [6].

Supply chains should improve their sustainability performance in three economic, environmental, and social areas [1] and at the same time, they must address the damage and uncertainty caused by the business environment [3]. Some researchers consider sustainability as the factor of enhancing company performance [26] and some consider resilience as a competitive resource instead of a risk-reducing tool [16]. Sustainability generally focuses on the long-term survival of the system [13], while resilience prolongs the organization's lifetime through dealing with disturbances [24].

Early efforts to integrate resilience concepts dates back to 1995 [34]. Rosic et al. found out that both resilience and sustainability approaches must be taken into account in the supply chain management just to enhance its overall performance [31]. Stonebraker et al. described the use of disruption management strategies as well as the reduction of environmental effects as the basic need in the supply chain [35]. Azevedo et al. (2012) proposed the integration of resilience and sustainability approaches given the vulnerability of reducing costs besides making a sustainable supply chain in the automotive industry [5]. Furthermore, Rajesh, Negri et al., and Sadeghi et al. (2021) emphasized the integration of two resilience and sustainability approaches as well as carrying out further research in this area through studying recent catastrophes [24, 28, 31]. Some researchers also believe that the ultimate goal of the system is resilience, and that sustainability is a process that helps this goal [39].

The first section of the current paper presents an introduction to the resilient and sustainable supply chain and the second section provides 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 by the fifth section.

2 Research background

Different researchers including Fiksel, Rosic et al. , Stonebraker et al., Carvalho et al. , and Azevedo et al. emphasized the integration of resilience and sustainability concepts in the supply chain [5, 6, 11, 31, 35]. 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 [9]. Mari et al. provided an ideal programming model for minimizing costs, carbon emissions, and disruption costs for the resilient and sustainable forward supply chain network under definitive conditions [19]. Besides, Mari et al. developed their previous model, presenting a mixed integer linear programming model for the resilient and sustainable logistics supply chain network [20]. Kaur and Singh 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 [14]. Zahiri et al. 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 [36]. Mousavi Ahranjani et al. 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 [22]. In their mathematical model, Zare Mehrjerdi and Shafiee utilized multiple sourcing strategies, shared information for resilience and minimization of costs, energy consumption, pollution, and maximization of job opportunities for sustainability of supply chain, and solved it through using the Epsilon Constraint method [38]. Zamanian et al. 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 Epsilon Constraint method [37].

Hosseini Motlagh et al. presented a robust resilient and sustainable mathematical model for 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% [12]. Lotfi et al. 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 [18]. Sadeghi et al. presented a robust mathematical model for the resilient and sustainable forward supply chain network and solved it using the Epsilon Constraint method [32]. Moreover, Nayeri et al. solved their robust mathematical model of resilient and sustainable supply chain with Multi-Choice Meta-Goal Programming Associated with a Utility Function [23].

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 through considering different operations such as modification, reuse, remanufacturing, and recycling, as well as burying the returned products [4, 40]. 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.

3 Statement of the problem

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.

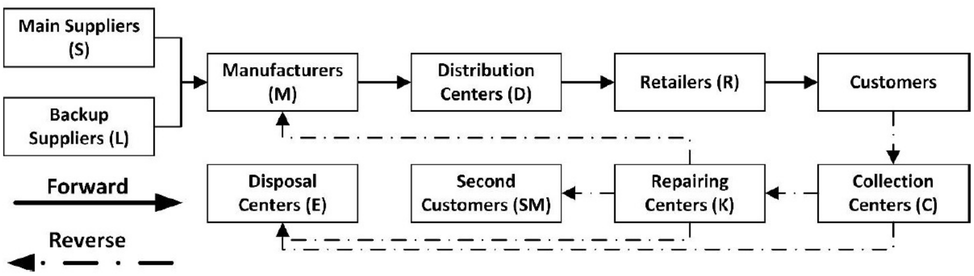

Figure 1: Proposed CLSC network

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 that the suppliers cannot fulfill their responsibilities for any reason, the responsibility of supplying raw materials is taken over by the backup suppliers.

4 The problem assumptions

- 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	$s \in \{1.2.3.\cdots.S\}$	Repairing Centers	$k \in \{1.2.3.\cdots.K\}$
Backup suppliers	$l \in \{1.2.3.\cdots.L\}$	Disposal centers	$e \in \{1.2.3.\cdots.E\}$
Manufacturers	$m \in \{1.2.3.\cdots.M\}$	Second customers	$sm \in \{1.2.3.\cdots.SM\}$
Distribution centers	$d \in \{1.2.3.\cdots.D\}$	products	$p \in \{1.2.3.\cdots.P\}$
Retailers	$r \in \{1.2.3.\cdots.R\}$	Raw materials	$sp \in \{1.2.3.\cdots.SP\}$
Collection Centers	$c \in \{1.2.3.\cdots.C\}$	Scenarios of disruption in suppliers	$sc \in \{1.2.3.\cdots.SC\}$

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	vsm_{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	$vksm^{p}_{ksm}$	Amount of pollution provided unit sp by s	es^{sp}_{s}
Variable cost of maintaining unit p in d	vcd^{p}_{d}	Amount of pollution caused produce unit p by m	em^{p}_{m}
Variable cost of maintaining unit p in r	vcr^{p}_{r}	Amount of pollution caused maintain unit p in d	ed^{p}_{d}
Variable cost of maintaining unit p in c	vcc^{p}_{c}	Amount of pollution caused maintain unit p in r	er^{p}_{r}
Variable cost of maintaining unit p in k	vck^{p}_{k}	Amount of pollution caused maintain unit p in c	ec^{p}_{c}
Energy use for produce one unit sp by supplier	ns^{sp}_{s}	Amount of pollution caused repair unit p in k	ek^{p}_{k}
Energy use for produce one unit p in m	nm^{p}_{m}	Amount of pollution caused disposal unit p in e	ee^{p}_{e}
Energy use for maintain one unit p in d	nd^{p}_{d}	Amount of pollution caused by transporting product p from s to m	esm^{sp}_{sm}
Energy use for maintain one unit p in r	nr^{p}_{r}	Amount of pollution caused by transporting product p from m to d	emd^{p}_{md}
Energy use for maintain one unit p in c	nc^{p}_{c}	Amount of pollution caused by transporting product p from d to r	edr^{p}_{dr}
Energy use for repair one unit p in k	nk^{p}_{k}	Amount of pollution caused by transporting product p from r to c	erc^{p}_{rc}
Energy use for destroy one unit p in e	ne^{p}_{e}	Amount of pollution caused by transporting product p from c to k	eck^{p}_{ck}
Energy use for transport unit sp from s to m	nsm^{sp}_{sm}	Amount of pollution caused by transporting product p from k to m	ekm^{p}_{km}
Energy use for transport unit p from m to d	nmd^{p}_{md}	Amount of pollution caused by transporting product p from k to sm	$eksm^{p}_{ksm}$
Energy use for transport unit p from d to r	ndr^{p}_{dr}	Amount of pollution caused by transporting product p from k to e	eke^{p}_{ke}
Energy use for transport unit p from r to c	nrc^{p}_{rc}	Capacity of main supplier s for sp	$caps^{p}_{s}$
Energy use for transport unit p from c to k	nck^{p}_{ck}	Capacity of manufacturer m for p	$capm^{p}_{m}$
Energy use for transport unit p from k to sm	$nksm^{p}_{ksm}$	Capacity of distribution center d for p	$capd^{p}_{d}$
Energy use for transport unit p from k to e	nke^{p}_{ke}	Capacity of retailer r for p	$capr^{p}_{r}$
Energy use for transport unit p from k to m	nkm^{p}_{km}	Capacity of collection center c for p	$capc^{p}_{c}$
The probability of occurrence of sc scenario	pr^{sc}	Capacity of repair center k for p	$capk^{p}_{k}$
Percentage of products delivered to collection centers	βr^{p}	Capacity of disposal center e for p	$cape^{p}_{e}$
Amount of pollution caused by transporting product p from c to e	ece^{p}_{ce}	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	$capl^{sp}_{l}$

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}

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}		

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

$$\min TCOST^{st} = \text{Fixed Cost} + \text{Variable Cost}^{sc} + \text{Inventory Cost}^{sc} \quad \forall sc \tag{4.1}$$

$$\begin{aligned}
\text{Fixed Cost} = & \sum_s fcs_s \times xs_s + sum_s fcl_l \times xl_l + \sum_m fcm_m \times xm_m + \sum_d fcd_d \times xd_d + \sum_r fcr_r \times xr_r \\
& + \sum_c fcc_c \times xc_c + \sum_k fck_k \times xk_k + \sum_e fce_e \times xe_e + \sum_p \sum_{sc} \sum_d \sum_r ydr_{dr}^{psc} \times cdr_{dr} \\
& + \sum_p \sum_{sc} \sum_m \sum_d ymd_{md}^{psc} \times cmd_{md} + \sum_{sp} \sum_{sc} \sum_s \sum_m ysm_{sm}^{spsc} \times csm_{sm} + \sum_p \sum_{sc} \sum_k \sum_{sm} yck_{ck}^{psc} \times cck_{ck} \\
& + \sum_{sp} \sum_{sc} \sum_l \sum_m ysml_{lm}^{spsc} \times vsml_{lm} + \sum_p \sum_{sc} \sum_k \sum_{sm} yksm_{ksm}^{psc} \times vksm1_{ksm} \\
& + \sum_p \sum_{sc} \sum_k \sum_m ykm_{km}^{psc} \times vkm1_{km} \\
\text{Variable Cost}^{sc} = & \sum_{sp} \sum_s \sum_m vcs_s^{sp} qsm_{sm}^{spsc} + \sum_{sp} \sum_l \sum_m vcsl_l^{sp} qsml_{lm}^{spsc} + \sum_p \sum_m \sum_d vcm_m^p qd_{md}^{psc} \\
& + \sum_m \sum_p pp_m^{sc} \times costp_p + \sum_{sp} \sum_s \sum_m vsm_{sm}^{sp} qsm_{sm}^{spsc} + \sum_{sp} \sum_l \sum_m vsml2_{lm}^{sp} qsml_{lm}^{spsc} \\
& + \sum_p \sum_d \sum_r vdr_{dr}^p qr_{dr}^{psc} + \sum_p \sum_r \sum_c vrc_{rc}^p qc_{rc}^{psc} + \sum_p \sum_c \sum_k vck_{ck}^p qk_{ck}^{psc} + \sum_p \sum_k \sum_e vke_{ke}^p qke_{ke}^{psc} \\
& + \sum_p \sum_k \sum_e vkm_{km}^p qkm_{km}^{psc} + \sum_p \sum_k \sum_{sm} vksm_{ksm}^p qksm_{ksm}^{psc} + \sum_p \sum_m \sum_d qmd_{md}^{psc} vmd1_{md}^p \\
& + \sum_p \sum_c \sum_e qce_{ce}^{psc} vcel_{ce}^p + \sum_p \sum_c \sum_k vck_k^p qk_{ck}^{psc} \\
\text{Inventory Cost}^{sc} = & \sum_p \sum_m \sum_d vcd_d^p qd_{md}^{psc} + \sum_p \sum_d \sum_r vcr_r^p qr_{dr}^{psc} + \sum_p \sum_r \sum_c vcc_c^p qsm_{rc}^{psc}
\end{aligned}$$

Equation (4.1) 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

$$\min TEnv^{sc} = Eng^{sc} + Ems^{sc} + Wtr^{sc} \quad ;\forall sc \tag{4.2}$$

$$\begin{aligned}
Eng^{sc} = &\sum_{sp}\sum_{s}\sum_{m}(ns_s^{sp} + nsm_{sm}^{sp})qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m}(nsl_l^{sp} + nsml_{lm}^{sp})qsml_{lm}^{spsc} \\
&+ \sum_{p}\sum_{m}\sum_{d}(nm_m^p + nmd_{md}^p)qmd_{md}^{psc} + \sum_{p}\sum_{d}\sum_{r}(nd_d^p + ndr_{dr}^p)qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c}(nr_r^p + nrc_{rc}^p)qc_{rc}^{psc} \\
&+ \sum_{p}\sum_{c}\sum_{k}(nc_c^p + nck_{ck}^p)qk_{ck}^{psc} + \sum_{p}\sum_{e}\sum_{k}(ne_e^p + nke_{ke}^p)qke_{ke}^{psc} + \sum_{p}\sum_{m}\sum_{k}(nm_m^p + nkm_{km}^p)qkm_{km}^{psc} \\
&+ \sum_{p}\sum_{sm}\sum_{k}(nk_k^p + nksm_{ksm}^p)qksm_{ksm}^{psc} + \sum_{p}\sum_{c}\sum_{e}(ne_e^p + nce_{ce}^p)qce_{ce}^{psc} \\
Ems^{sc} = &\sum_{sp}\sum_{s}\sum_{m}(es_s^{sp} + esm_{sm}^{sp})qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m}(esl_l^{sp} + eslm_{lm}^{sp})qsml_{lm}^{spsc} \\
&+ \sum_{p}\sum_{m}\sum_{d}(em_m^p + emd_{md}^p)qd_{md}^{psc} + \sum_{p}\sum_{d}\sum_{r}(ed_d^p + edr_{dr}^p)qr_{dr}^{psc} + \sum_{p}\sum_{r}\sum_{c}(er_r^p + erc_{rc}^p)qc_{rc}^{psc} \\
&+ \sum_{p}\sum_{c}\sum_{k}(ec_c^p + eck_{ck}^p)qk_{ck}^{psc} + \sum_{p}\sum_{e}\sum_{k}(ee_e^p + eke_{ke}^p)qke_{ke}^{psc} + \sum_{p}\sum_{m}\sum_{k}(em_m^p + ekm_{km}^p)qkm_{km}^{psc} \\
&+ \sum_{p}\sum_{sm}\sum_{k}(ek_k^p + eksm_{ksm}^p)qksm_{ksm}^{psc} + \sum_{p}\sum_{c}\sum_{e}(ee_e^p + ece_{ce}^p)qce_{ce}^{psc} \\
Wtr^{sc} = &\sum_{sp}\sum_{s}\sum_{m} ws_s^{sp}qsm_{sm}^{spsc} + \sum_{sp}\sum_{l}\sum_{m} ws_l^{sp}qsml_{lm}^{spsc} + \sum_{p}\sum_{m}\sum_{d} wm_m^p qd_{md}^{psc} + \sum_{p}\sum_{d}\sum_{r} wd_d^p qr_{dr}^{psc} \\
&+ \sum_{p}\sum_{r}\sum_{c} wr_r^p qc_{rc}^{psc} + \sum_{p}\sum_{c}\sum_{k} wc_c^p qk_{ck}^{psc} + \sum_{p}\sum_{k}\sum_{c} wk_k^p qk_{ck}^{psc} + \sum_{p}\sum_{k}\sum_{e} we_e^p qke_{ke}^{psc} \\
&+ \sum_{p}\sum_{c}\sum_{e} we_e^p qce_{ce}^{psc}
\end{aligned}$$

Equation (4.2) 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 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

$$\begin{aligned}
\max\ s\ Res = &\sum_{s}\sum_{p} os_s^p xs_s + \sum_{l}\sum_{sp} oel_l^{sp} xl_l + \sum_{m}\sum_{p} om_m^p xm_m + \sum_{m}\sum_{p} od_d^p xd_d \\
&+ \sum_{r}\sum_{p} orr_r^p xr_r + \sum_{k}\sum_{p} ok_k^p xc_c + \sum_{k}\sum_{p} oe_e^p xe_e
\end{aligned} \tag{4.3}$$

Equation (4.3) shows the third target function maximizing the number of jobs created by the construction of the facility.

5 Constraints

$$hh_{sp} \times pp_m^{sp} = \sum_{s}(qsm_{sm}^{spsc}/(1 - delts_s^{sc})) + \sum_{l}(qsml_m^{spsc}/(1 - deltl_l^{sc})); \quad \forall m.sc.sp \tag{5.1}$$

$$(1-\alpha)\sum_r qc_{rc}^{psc} = \sum_e qce_{ce}^{psc}; \quad \forall c.p.sc \tag{5.2}$$

$$\sum_k qk_{ck}^{psc} = \alpha \sum_r qc_{rc}^{psc}; \quad \forall c.p.sc \tag{5.3}$$

$$\sum_{sm} qksm_{ksm}^{psc} = \beta \sum_c qk_{ck}^{psc}; \quad \forall k.p.sc \tag{5.4}$$

$$\sum_m qkm_{km}^{psc} = (1-(\beta+\gamma)) \sum_c qk_{ck}^{psc}; \quad \forall r.p.sc \tag{5.5}$$

$$\sum_e qke_{ke}^{psc} = \gamma \sum_c qk_{ck}^{psc}; \quad \forall k.p.sc \tag{5.6}$$

$$\sum_{sc}\sum_d qr_{dr}^{psc} \geq d_r^p; \quad \forall r.p \tag{5.7}$$

$$ydr_{dr}^{psc} \leq xd_d; \quad \forall r.d.p.sc \tag{5.8}$$

$$ymd_{md}^{psc} \leq xm_m; \quad \forall d.m.p.sc \tag{5.9}$$

$$ykm_{km}^{psc} \leq xm_m; \quad \forall p.sc.k.m \tag{5.10}$$

$$ykm_{km}^{psc} \leq xk_m; \quad \forall p.sc.k.m \tag{5.11}$$

$$yksm_{ksm}^{psc} \leq xk_k; \quad \forall p.sc.k.sm \tag{5.12}$$

$$ysm_{sm}^{psc} \leq xs_s; \quad \forall s.m.p.sc \tag{5.13}$$

$$ysml_{lm}^{spsc} \leq xl_l; \quad \forall l.m.p.sc \tag{5.14}$$

$$ysm_{sm}^{spsc} \leq xm_m; \quad \forall s.m.p.sc \tag{5.15}$$

$$qc_{rc}^{psc} \leq xc_c capr_r^p; \quad \forall r.p.sc.c \tag{5.16}$$

$$qk_{ck}^{psc} \leq xk_k capk_k^p; \quad \forall c.k.p.sc \tag{5.17}$$

$$\sum_k qke_{ke}^{psc} \leq cape_e^p; \quad \forall e.p.sc \tag{5.18}$$

$$qmd_{md}^{psc} \leq xd_d capd_d^p; \quad \forall m.d.p.sc \tag{5.19}$$

$$\sum_d qmd_{md}^{psc} \leq capm_m^p \times xm_m; \quad \forall s.m.p.sc \tag{5.20}$$

$$qsm_{sm}^{spsc} \leq BIGM \times ysm_{sm}^{spsc}; \quad \forall s.sp.sc.m \tag{5.21}$$

$$qsml_{lm}^{spsc} \leq BIGM \times ysml_{lm}^{spsc}; \quad \forall l.sp.sc.m \tag{5.22}$$

$$qmd_{md}^{psc} \leq BIGM \times ymd_{md}^{psc}; \quad \forall m.d.p.sc \tag{5.23}$$

$$qr_{md}^{psc} \leq BIGM \times ydr_{dr}^{psc}; \quad \forall r.d.p.sc \tag{5.24}$$

$$qk_{ck}^{psc} \leq BIGM \times yck_{ck}^{psc}; \quad \forall c.k.p.sc \tag{5.25}$$

$$qkm_{km}^{psc} \leq BIGM \times ykm_{km}^{psc}; \quad \forall p.sc.k.m \tag{5.26}$$

$$qksm_{ksm}^{psc} \leq BIGM \times yksm_{ksm}^{psc}; \quad \forall sm.k.p.sc \tag{5.27}$$

$$\sum_s ysm_{sm}^{spsc} \leq 1; \quad \forall sp.sc.m \tag{5.28}$$

$$\sum_l ysml_{lm}^{spsc} \leq 1; \quad \forall p.sc.m \tag{5.29}$$

$$\sum_m ymd_{md}^{psc} \leq 1; \quad \forall d.p.sc \tag{5.30}$$

$$\sum_d ydr_{dr}^{psc} \leq 1; \quad \forall r.p.sc \tag{5.31}$$

$$\sum_k ykm^{psc}_{km} \leq 1; \quad \forall p.sc.m \tag{5.32}$$

$$\sum_k yksm^{psc}_{ksm} \leq 1; \quad \forall p.sc.sm \tag{5.33}$$

$$qke^{psc}_{ke} \leq BIGM \times xe_e; \quad \forall e.k.p.sc \tag{5.34}$$

$$qce^{psc}_{ke} \leq BIGM \times xe_e; \quad \forall e.k.p.sc \tag{5.35}$$

$$\sum_{sp}\sum_{m} qsm^{spsc}_{sm}/(1 - delts^{sc}_s) \leq (1 - GS^{sc}_s) \times caps_s \times xs_s; \quad \forall s.sc \tag{5.36}$$

$$\sum_{sp}\sum_{m} qsml^{spsc}_{lm}/(1 - deltl^{sc}_l) \leq (1 - GS^{sc}_s) \times capl_l \times xl_l; \quad \forall l.sc \tag{5.37}$$

$$xl_l.xs_s.xm_m.xd_d.xr_r.xc_c.xk_k.xe_e.ysm^{spsc}_{sm}.ymd^{psc}_{md}.ydr^{psc}_{dr}.yrc^{psc}_{rc}.yck^{psc}_{ck}.ysml^{spsc}_{lm}.ykm^{psc}_{km}.yksm^{psc}_{ksm}.yke^{psc}_{ke} \in \{0.1\} \tag{5.38}$$

$$qce^{psc}_{ce}.qsm^{spsc}_{sm}.qd^{psc}_{md}.qr^{psc}_{dr}.qc^{psc}_{rc}.qk^{psc}_{ck}.qke^{psc}_{ke}.qkm^{psc}_{km}.qksm^{psc}_{ksm}.qmd^{psc}_{md}.qsml^{spsc}_{lm} \geq 0.Int \tag{5.39}$$

Constraint (5.1) 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 (5.6) shows the amount of unrepairable products from returned products transferred from collection and inspection centers to disposal centers. Constraint (5.7) shows the amount of returned products sent from the collection and inspection centers to repair centers. Constraint (5.8) shows the amount of products repaired in the repair centers and shipped to the second market. Constraint (5.9) shows the amount of high quality repaired products shipped from the repair centers to manufacturers for recycle. Constraint (5.10) shows the amount of unrepairable products shipped from the repair centers to disposal centers. Constraint (5.11) ensures that customer demand is fully fulfilled. Constraints (5.12) to (5.19) guarantee that sending from any facility depends on constructing it. Constraints (5.20), (5.24) show that the entry of products to the facilities or exit of the product from them should not exceed their capacity. Constraints (5.25) to (5.37) relate to the allocation of facilities. Constraints (5.38) and (5.39) are related to the location of the disposal centers. Constraints (6.1) and (6.2) show the amount of raw materials prepared by the main and backup suppliers in different scenarios. Constraints (6.3) and (6.4) are related to the binary, positive, and integer nature of the decision variables.

6 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^p_r) we have ($d1^p_r.d2^p_r.d3^p_r.d4^p_r$) whose definitive equivalent is calculated as follows based on [21]:

$$EV[\tilde{\xi}] = \frac{\xi_1.\xi_2.\xi_3.\xi_4}{4} \tag{6.1}$$

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:

$$\xi_1 = 0.6 \times \xi_3;\ \xi_2 = 0.8 \times \xi_3;\ \xi_3 = \xi;\ \xi_4 = 1.4 \times \xi_3 \tag{6.2}$$

Pishvaee et al.'s robust possibilistic programming (RPP) model (2012) 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:

$$\min TCOST^{sc} = \text{Fixed Cost} + \text{Variable Cost}^{sc} + \text{Inventory Cost}^{sc} + \pi \times (d4_r^p - (\alpha \times d4_r^p + (1-\alpha) \times d3_r^p) \tag{6.3}$$
$$+ \varphi \times (\beta \times GS1_s^{sc} + (1-\beta) \times GS2_s^{sc}) - GS1_s^{sc}) \qquad \forall sc$$

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

$$\text{Variable Cost}^{sc} = \sum_{sp} \sum_s \sum_m \frac{vcs1_s^{sp} + vcs2_s^{sp} + vcs3_s^{sp} + vcs4_s^{sp}}{4} qsm_{sm}^{spsc}$$
$$+ \sum_{sp} \sum_l \sum_m \frac{vcsl1_l^{sp} + vcsl2_l^{sp} + vcsl3_l^{sp} + vcsl4_l^{sp}}{4} qsml_{lm}^{spsc}$$
$$+ \sum_p \sum_m \sum_d \frac{vcm1_m^p + vcm2_m^p + vcm3_m^p + vcm4_m^p}{4} qd_{md}^{psc}$$
$$+ \sum_m \sum_p pp_m^{sc} \times \frac{cost1_p + cost2_p + cost3_p + cost4_p}{4}$$
$$+ \sum_{sp} \sum_s \sum_m \frac{vsm1_{sm}^{sp} + vsm2_{sm}^{sp} + vsm3_{sm}^{sp} + vsm4_{sm}^{sp}}{4} qsm_{sm}^{spsc}$$
$$+ \sum_{sp} \sum_l \sum_m \frac{vsmll1_{lm}^{sp} + vsmll2_{lm}^{sp} + vsmll3_{lm}^{sp} + vsmll4_{lm}^{sp}}{4} qsml_{lm}^{spsc}$$
$$+ \sum_p \sum_d \sum_r \frac{vdr1_{dr}^p + vdr2_{dr}^p + vdr3_{dr}^p + vdr4_{dr}^p}{4} qr_{dr}^{psc}$$
$$+ \sum_p \sum_r \sum_c \frac{vrc1_{rc}^p + vrc2_{rc}^p + vrc3_{rc}^p + vrc4_{rc}^p}{4} qc_{rc}^{psc}$$
$$+ \sum_p \sum_c \sum_k \frac{vck1_k^p + vck2_k^p + vck3_k^p + vck4_k^p}{4} qk_{ck}^{psc}$$

$$+\sum_{p}\sum_{k}\sum_{e}\frac{vke1^p_{ke}+vke2^p_{ke}+vke3^p_{ke}+vke4^p_{ke}}{4}qke^{psc}_{ke}$$
$$+\sum_{p}\sum_{k}\sum_{e}\frac{vkm1^p_{km}+vkm2^p_{km}+vkm3^p_{km}+vkm4^p_{km}}{4}qkm^{psc}_{km}$$
$$+\sum_{p}\sum_{m}\sum_{d}qmd^{psc}_{md}\frac{vmd1_{md}+vmd2_{md}+vmd3_{md}+vmd4_{md}}{4}$$
$$+\sum_{p}\sum_{c}\sum_{k}\frac{vck1^p_{k}+vck2^p_{k}+vck3^p_{k}+vck4^p_{k}}{4}qk^{psc}_{ck}$$
$$+\sigma\times(\text{Variable Cost Parameters (4)}\times\text{Variables})$$
$$\text{Inventory Cost}^{sc}=\sum_{p}\sum_{m}\sum_{d}\frac{vcd1^p_{d}+vcd2^p_{d}+vcd3^p_{d}+vcd4^p_{d}}{4}qd^{psc}_{md}$$
$$+\sum_{p}\sum_{d}\sum_{r}\frac{vcr1^p_{r}+vcr2^p_{r}+vcr3^p_{r}+vcr4^p_{r}}{4}qr^{psc}_{dr}$$
$$\sum_{p}\sum_{r}\sum_{c}\frac{vcc1^p_{c}+vcc2^p_{c}+vcc3^p_{c}+vcc4^p_{c}}{4}qsm^{psc}_{rc}$$
$$+\sigma\times(\text{Inventory Costs Parameters (4)}\times\text{Variables})$$

Moreover, Restrictions (5.7) and (5.36) are examined under uncertainty, the definitive equivalent of which is (6.4), (6.5):

$$\sum_{sc}\sum_{d}qr^{psc}_{dr}\geq\alpha\times d4^p_r+(1-\alpha)\times d3^p_r;\qquad\forall r.p \tag{6.4}$$

$$\sum_{sp}\sum_{m}qsm^{spsc}_{sm}/(1-delts^{sc}_s)\leq(1-(\beta\times GS1^{sc}_s+(1-\beta)\times GS2^{sc}_s))\times caps_s\times xs_s;\qquad\forall s.sc \tag{6.5}$$

7 Solving method

Augmented Epsilon Constraint (AEC) method is used to solve the multi-objective model provided. The overall form of a multi-objective problem is as:

$$\begin{cases}\min(f_1(x)\cdot f_2(x)\cdot\ldots\cdot f_n(x))\\ x\in X\end{cases} \tag{7.1}$$

in the Equation (7.1), the first objective constrained to the primary target and other targets to the maximum Epsilon (e_i) and applied to the Restrictions of the problem. Subsequently, the Epsilon method is used and the following single-objective model is obtained:

$$\begin{cases}\min f_1(x)\\ f_i(x)\leq e_i\quad i=2.3.\cdots.n\\ x\in X\end{cases} \tag{7.2}$$

By changing the e_i values in the Epsilon constraint method, different answers are obtained that may be effective or efficient. By modifying or completing the model (7.2), the efficient responses can be reached, called Augmented Epsilon Constraint (AEC) [38]. In this method, first the appropriate interval of Epsilon (e_i) must be determined using the payoff matrix; of course, perhaps the efficient response is not achieved for some Epsilon values. Then, the Pareto front is obtained for different Epsilon values.

To find the right interval for e_i related to the i target ($i=2,...,n$), the optimization problems (7.7) must first be resolved for each of the targets ($j=1,2,...,n$):

$$\text{Pay Off}_{jj}=\min f_i(x);\quad x\in X \tag{7.3}$$

where x^{j*} is saved as an optimal answer and $PayOff_{jj}=f_i(x^{j*})$ as an optimized j value: then, the j target's optimal value should be obtained while each time one of the targets of $j=1,2,...,n; j\neq i$ should be in the optimal conditions as (7.4).

$$\begin{cases} \text{Pay Off}_{jj} = \min f_i(x) \\ f_i(x) = \text{Pay Off}_{jj} \\ x \in X \\ j \neq i \end{cases} \quad (7.4)$$

where the optimized response x^{ij*} is calculated with the optimal value $PayOff_{jj} = f_i(x^{ij*})$ for the target i. Now using the Lexicographic method, the payoff matrix (7.5), a 3×3 matrix in this study, is obtained:

$$PayOff = [payOff_{ij}] \quad (7.5)$$

After determining the payoff matrix, the following options are defined for the target $i = 1, ..., n$ ((7.6), (7.7), and (7.8)):

$$\min(f_i) = \min_j \{payOff_{ij}\} = payOff_{ii} \quad (7.6)$$

$$\max(f_i) = \max_j \{payOff_{ij}\} \quad (7.7)$$

$$R(f_i) = \max(f_i) - \min(f_i) \quad (7.8)$$

According to the above definition, the appropriate e_i interval is determined as $e_i \in [\min(f_i) \cdot \max(f_i)]$. Moreover, the value of $R(f_i)$ is used to normalize the targets in the augmented ε-constraint function [38]. The programming model (7.9) is developed below:

$$\begin{cases} \min z = f_1(x) - \emptyset_2 s_2 + \emptyset_3 s_3 \\ f_2(x) + s_2 = e_2 \\ f_3(x) + s_3 = e_3 \\ x \in X \\ S_2.S_3 \geq 0 \end{cases} \quad (7.9)$$

8 Numerical results

A problem in the form of table 1 was considered in order to evaluate the performance of the presented model:

Table 1: problem information

sc	sp	p	sm	e	k	c	r	d	m	l	s
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 software and by means of random data. The payoff matrix resulting from solving the model with the AEC method is as shown in Table 2:

Table 2: payoff matrix resulting from solving the model by AEC method

	F1	F2	F3
F1	60210.86	82829.79	95430.425
F2	47568.71	32698.78	32698.78
F3	53	108	108

Besides, the Pareto front resulting from solving the model using AEC method is exhibited in Fig. 2.

Fig. 3 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.

In order to analyze the problem and draw its schematic, the flow of products and the location of one of the Pareto points specified in Fig. 2 are reported:

Given the dimensions of the considered problem, at the specified point, two main suppliers are active due to the level of disruption, and both backup suppliers are employed to meet the producers' needs. All of the two factories, two distribution centers, five retail centers, and three collection centers have been constructed, and one center out of

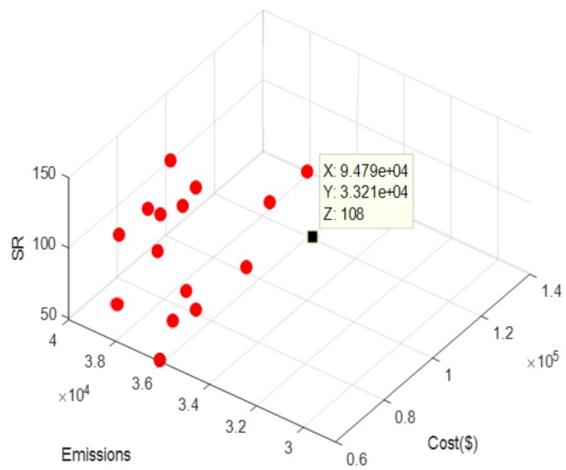

Figure 2: Pareto front created by AEC method

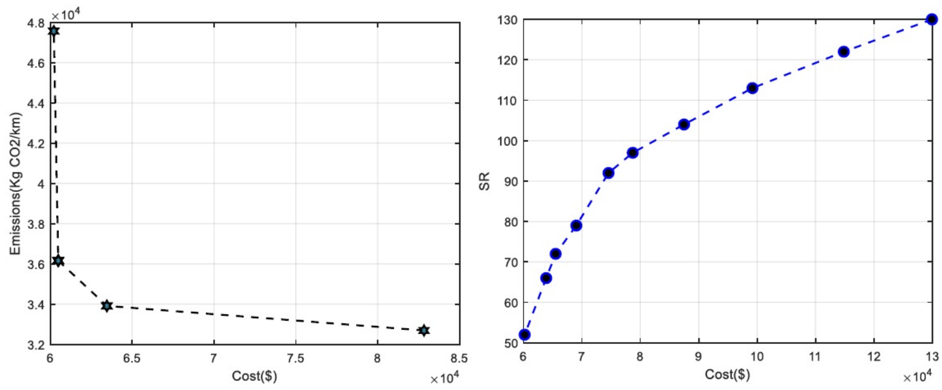

Figure 3: Conflict between economic-environmental-social responsibility goals

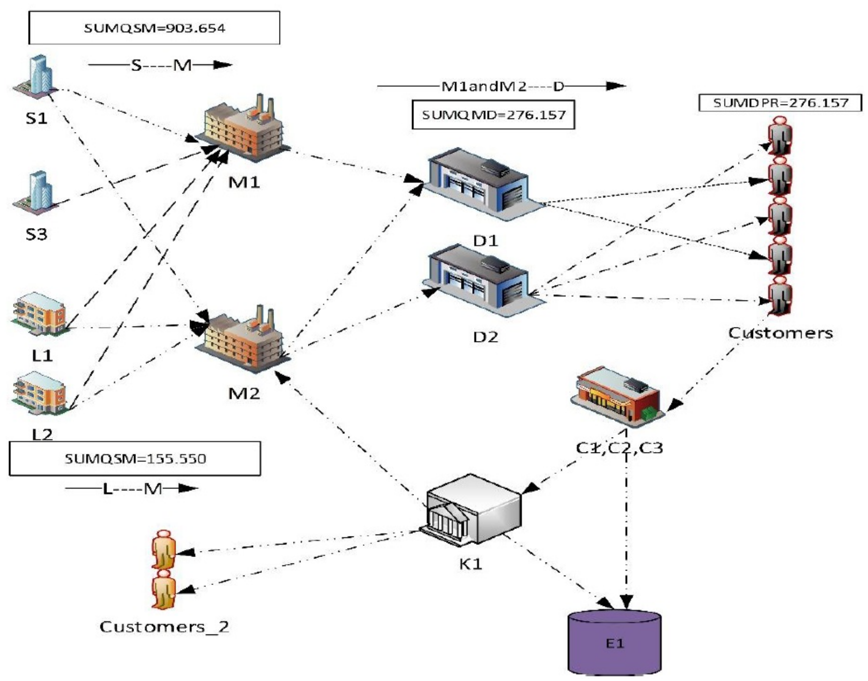

Figure 4: Schematic result of solving the proposed mathematical model

two repair centers and two disposal centers has been constructed. The reason for the construction of most centers is that social responsibility at this Pareto point is at its highest level.

Fig. 4 exhibits the schematic result of solving the model and its validity. Accordingly, the total customer demand is 276.375, which is equal to the customer demand based on the assumption of meeting all customers' demand, the total amount of products shipped from the factory to the distribution center and from the distribution center to the customers.

Consider the following parameters in order to analyze resilience:

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

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 41 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. 5 shows the increase in costs in case of disruption of 40-80%.

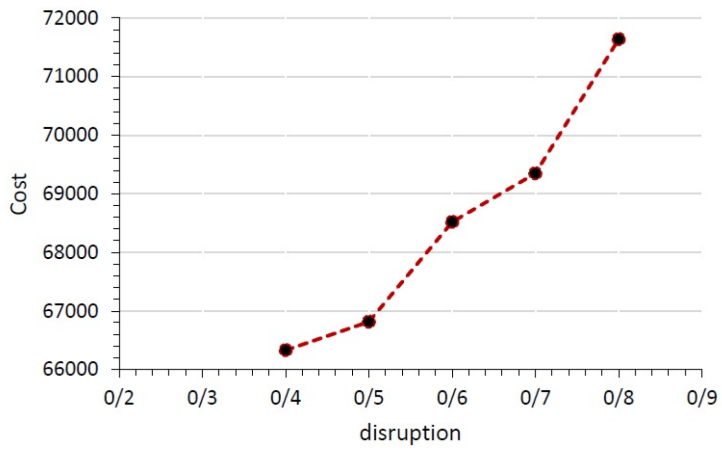

Figure 5: Relationship between disruption and cost

Figs. 6, 7, and 8 show the effect of decreasing the capacity of the main suppliers without causing disruption on the target functions:

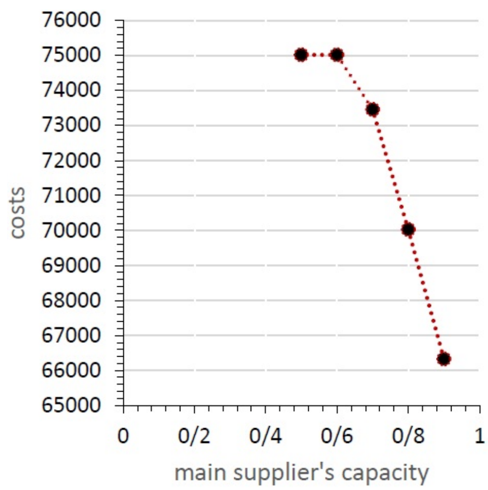

Figure 6: Relationship between the main supplier's capacity and costs

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

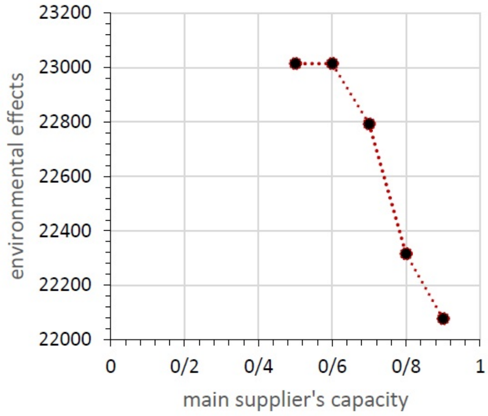

Figure 7: Relationship between the main supplier's capacity and environmental effects

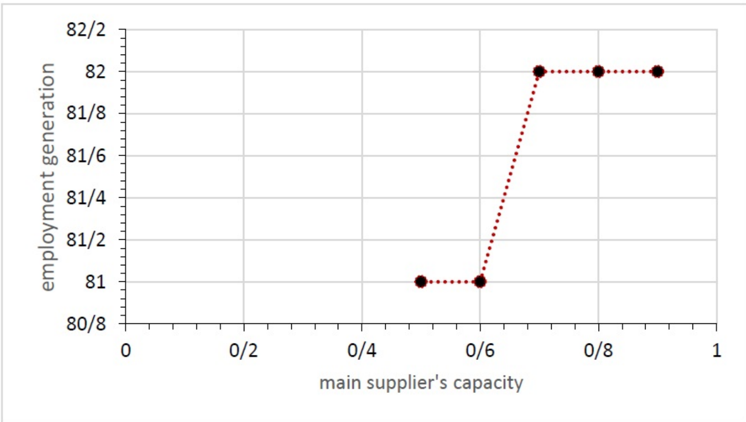

Figure 8: Relationship between the main supplier's capacity and employment generation

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.

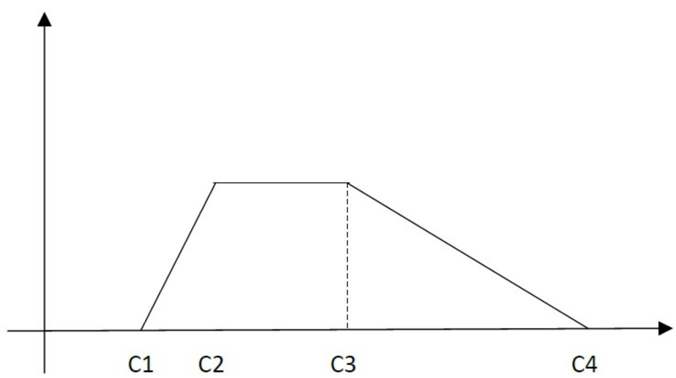

Figure 9: Fuzzy parameters with trapezoidal distribution

Based on Fig. 9, 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.

$$Epsilon2 = (MinFunction(obj2) + MaxFunction(obj2))/2 + RangFunction(obj2)uniform(-1, 0.8)/2$$
$$Epsilon3 = (MinFunction(obj3) + MaxFunction(obj3))/2 + RangFunction(obj3)uniform(-1, 0.8)/2$$

After executing the model in the above-mentioned output modes, the resulting output is visible in Table 3.

Table 3: 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	61415.97	36736.85	59	87437.12	44036.731	59
2	0.8	63173.4	42318.86	59			
3	0.9	66271.21	43600.99	59			

The results suggest that the increased minimum possibilistic degree has led to the increased costs due to increased demand and other parameters under conditions of uncertainty and the costs in possibilistic programming model is lower at the confidence level of 0.9 than the robust possibilistic programming model with a penalty of 0.5.

9 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. In the proposed model, it was assumed that after the raw materials arrived from suppliers to factories and manufacturers, the produced products are transferred to distributors and retailers and the customer demands would be met through retailers. Subsequently, a percentage of the used products are shipped to the collection and inspection centers, and after inspection, unrepairable items are shipped to the disposal centers and the rest to the repair centers. In repair centers, the returned products are shipped to the production centers in case of having the first quality and minor repairs and, if professional repair is needed and second or third quality level, they are shipped to the second-hand market and if not repaired, to the disposal centers.

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 resolved under certain conditions and the results were examined. 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. 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.

Considering the variety of vehicles with a variety of capacities may decline shipping costs. Furthermore, given the logistical disruptions, various transport operations, such as road, rail, air, and marine operations may be considered as parallel connectivity between the facilities, and in case of a problem for each route, alternative routes can be activated instead of the original route. Future research may investigate these issues.

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