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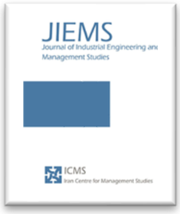

A multi-objective mathematical planning model for a multi-level sustainable supply chain considering market boom and downturn

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Abstract

A multi-level sustainable supply chain is related to a system that includes all activities necessary to transfer and supply materials and services from the producer to the consumer. In this system, the focus is on providing materials and services based on a number of objectives, such as reducing costs, increasing quality, and preserving the environment. Due to the increase of uncertainty in the supply chain, organizations need to use resources for the prediction of internal uncertainties, needs, and supply, thereby minimizing vulnerability and elevating the tolerance of their supply. Understanding the uncertainties and the parameters causing factors causes the problem of risk management to be raised in some cases. Therefore, main contribution of current study is multi-objective planning for a sustainable, multi-level, multi-period model, considering the determined conditions and boom as uncertainty scenarios, has been specifically considered. The most important goal of the research is to determine the best units of each level (suppliers, factories, ...) of chain networks according to the points and criteria determined in the model and network, design and determine the best communication routes (network) between the selected units Each level is optimal with other levels as well as determining the volume of transported goods in these routes. For this purpose, a mathematical model has been developed, which is solved through the limited epsilon method and NSGA-II meta-heuristic algorithm. Data comparing the mathematical model and NSGA-II meta-heuristic algorithm show the calculated errors of 0.022, which considering that it is less than 0.1, the calculation error is acceptable and can be compared to the results of the error methods. The sensitivity analysis on the probability of the boom scenario showed the value of the objective function can change between 7398.51 and 3245.73. Finally, the sensitivity analysis of the probability of recession scenario showed the value of the objective function can change between 3291.64 and 9364.35. The findings of this research show that using the multi-objective planning model in the sustainable supply chain, taking into account the boom and bust of the market, can create significant improvements in the performance and profitability of the supply chain.

Keywords: sustainable Supply chain, Uncertainty, Epsilon constraint, NSGA-II

Paper Type: Original Research

1. Introduction

In the 1980s, organizations focused more on systems such as just-in-time production, comprehensive quality management, etc., to achieve sustainable competitive advantage. With the expansion of these sciences in other factories and production centers, the primary function of these sciences becomes less and other competitors put themselves on par with other institutions with updated plans. In other words, keeping organizational processes up to date without considering external companies, especially suppliers and customers, seemed useless, and organizations that worked together towards common goals performed better. In other words, in today's modern world, supply chain networks refer to the axis of economic affairs. Their importance due to timely delivery, attention to economic and environmental aspects, and efficiency in various products such as food, clothing, energy, computer hardware, etc. have made researchers and experts interested in analyzing supply chain issues. (Rezaei et al., 2021; Khorshidvand et al. 2021a). A supply chain is a system consisting of organizations, people, technology, activities, information, and resources that participate in the production and transfer of goods and services from suppliers to customers. Business and environmental indices like the commitment and amount of risk they provide for their customers have caused reverse logistics networks to gain special importance. To achieve this, different dimensions of supply chain risks must be identified so that they can be managed (Alamdar et al., 2019). Uncertainty can be observed at a high level in supply chains because of their complexity, which can harm the quality of their behavior. Due to the importance of this, the uncertainty in parameters during supply chain development, with a possibility

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of intensification in the long-term horizon of decision-making, is divided into two categories (Wong et al., 2020; Khorshidvand et al. 2021b). Uncertainties in environmental and systemic parameters can adversely influence the supply chain (He et al., 2019). Therefore, in this research, uncertainty is used about parameters (demand parameters and product quality). When developing reverse logistics networks, the required number, location, and capacity of collection, recycling, and destruction centers, safety stock, and material flow between facilities are examined (Polo et al., 2019). Numerous studies have separately discussed the design of direct and reverse logistics networks, but the configuration of these two networks has a significant and mutual effect on each other. Also, design isolation can lead to sub-optimality (local optimum), so the design of reverse and forward logistics networks needs to be combined and integrated (Samuel et al., 2020; Khorshidvand et al. 2023). On the other hand, the environment's complexity and uncertainty deeply impact the activities of companies, especially their supply chain. As a result, the importance of supply chain sustainability is very important. Sustainability refers to an appropriate balance between economic development, and environmental and social stewardship. Therefore, in this research, we intend to examine the effective criteria in three economic, environmental, and social dimensions in the supply chain so that the designed supply chain can be sustainable. For this issue, the important and influential criteria in these three aspects are extracted and considered as a function of the objective and limitation of the problem (Fu et al., 2021; Khorshidvand et al. 2021c).

Understanding the supply chain risks faced by companies makes it possible for company managers to develop a better ability to recognize and deal with unexpected events. Identification of risks can be strategically a potential lever during the competitiveness of organizations. Uncertainty and risk in the supply chain have a significant impact on its shape, design, and operation. From the other point of view of trade and business, the existence of risk and uncertainties means that if there is no risk and danger in something, it will not have economic value because no added value will be created in that activity. Supply chain risk assessment can protect the business interests and brand of the organization against the basic and important concept of supply chain failure. Therefore, the most important goal of our work is to recognize the best units of each level (suppliers, factories, ...) of the supply chain network according to the parameters and criteria considered to optimize the model and network, design and determine the best routes (network) of communication between the selected units of each level with other levels, as well as determining the volume of transfer goods in these optimal routes. The most important contributions and innovations of this research are:

• Reducing the risk of a closed loop supply chain by reducing the risk of establishing new centers and also increasing the distance of establishing new centers from people's places of residence.

• Simultaneous consideration of economic, environmental, and social responsibility dimensions. Social responsibility is considered as maximizing employment and reducing personnel dismissal.

• Considering two scenarios of recession and boom to apply supply chain uncertainty to be closer to real state to examine risk reduction and sustainability aspects.

• Customizing the developed model for a case study on the actual matrix.

The rest of the paper is compiled as indicated. In the second part, a historical review of the literature is presented to clarify research gaps. In the third part, the developed approach is presented. To this end, while defining the problem; Mathematical modeling is presented along with the definition of all sets, parameters, variables, objective functions, and constraints. Modeling solution methods are also introduced. In the fourth section, the numerical results implemented in a case study on the actual matrix are presented. Finally, in the fifth section, a general conclusion is presented along with future suggestions.

2. Literature review

Risk value refers to the measurement or assessment of the potential risks associated with a specific event, action, or investment. It is a quantitative or qualitative representation of the likelihood and impact of potential negative events or outcomes. The risk value helps in determining the level of risk and making informed decisions regarding risk mitigation strategies (Heydari-Kushalshah et al., 2023; Khorshidvand et al. 2021d). Also, Risk value management is a process that involves identifying and assessing risks in order to determine their potential impact on an organization or project. It involves assigning a value or score to each risk based on factors such as likelihood, severity, and potential consequences. This helps prioritize risks and determine the best strategies for managing or mitigating them. The goal of risk value management is to minimize the negative impact of risks and maximize the potential benefits by making informed decisions and taking appropriate actions (Abolghasemian et al., 2021). In this section presents a historical review of past studies related to supply chain management in facing risk. Gitinavard et al. (2019) have presented a problem with the design of a multi-period supply chain network in which some practical features like financial decisions taken by the supply chain management company have been studied and analyzed. These decisions include facility location, material flow, and investment to create alternative activities for activities related to the design of the supply chain. Uncertainty in rates of interest and demand is defined by a collection of events. Also, an index called service level can also be estimated and inserted in the objective function. Various techniques have been used in modeling the supply chain network design problem. Kara et al. (2020)

explored value-supported integrated behavior and management of operational risk for planning a mid-term supply chain. A supply chain was considered from manufacturing to a warehouse with single-step generation in which uncertainty about demand and limitations about production capacity and at the same time flow of materials and data exist in the planning of sales operations regarding economic value based on the sustainable optimization method. Iqbal et al. (2020) have presented a mathematical approach to minimize the consumption of energy during the green chain. In their developed supply chain, waste materials are collected from customers and re-located to collection trucks, recycled from these areas, and re-applied as second-hand matters. The presented three-level and non-linear mathematical model aimed to drop the costs within the green chain. Based on the findings, the developed model could elevate the system efficiency up to 98.4%. Yun et al. (2020) designed a sustainable closed-loop supply chain based on environmental and socio-economic features. The considered contribution includes a reduction in overall cost, a decrease in the released CO2 level, and an increase in social impacts. The distribution channels considered in this research included normal delivery, direct delivery, and direct transfer. Finally, the model is solved with the combined genetic algorithm. Huang et al. (2020) modeled a closed-loop green supply chain regarding the released CO2. Therefore, a dual-objective model is presented to balance operational costs and environmental costs. Different capacity levels along with considering different environmental levels for facilities are among their innovations. The considered uncertainty is scenario-based and the epsilon limit approach is applied for solving the model. Rihani et al. (2020) developed a multi-objective mathematical model to achieve a sustainable closed-loop supply chain for agricultural products. The main objectives of the research are to determine the amount of flow at each level and locate the facility. Therefore, in this research, the minimization of costs and costs of carbon dioxide is released. The data show a good function of the developed model. Zhang et al. (2020) addressed the management of the amount of carbon released and used in the supply chain. Therefore, the research aimed to minimize transportation costs and stored and released carbon dioxide. In this research, the release of carbon dioxide is done by 15 different routes. The considered case study in North China is considered in the following scenarios: 1-source of freed square footage, 2-limitation of raw materials, and 3-product demand level. The data confirmed a good function for the developed model. Rabbani et al. (2020) introduced a multi-period and multi-objective model for location and allocation to achieve a sustainable supply chain. Regarding diverse methods for cars resulting in various costs, including CO2 release costs, is an innovation of this work. To bypass the problem uncertainty, the HRPP-II sustainable hybrid approach has been used. Finally, a case study is solved with the epsilon constraint approach, and obtains show the appropriate behavior of the developed model. Nasr et al. (2021) introduced a multi-objective fuzzy model in the closed-loop supply chain to reduce costs.

The introduced two-level model includes the selection of suppliers as well as their allocation to manufacturers. The research aimed to reduce the environmental and operational costs lost demand and maximize employment. Considered innovation deals with the sustainability of the supply chain. At last, the proposed model was solved via ideal optimization. Chang (2021) designed a dynamic competitive game within a closed-loop supply chain. The role of government in the developed supply chain was an innovation of this attempt. Hence, the government provides six diverse methods for the management of the chain using the Nash equilibrium. A reduction in environmental costs is an objective of the study. The results show the proper performance of the proposed model in dropping the developed supply chain cost. Fu et al. (2021) investigated the uncertainties in the closed-loop supply chain. Assessing the interplay between the reverse and direct chains is an essential action. The considered chain involved the manufacturer, distributor, and retailer. The work aimed to boost the profit of the chain along with a decrease in environmental costs. According to previous numerical samples in diverse dimensions, the outcome of the developed model was commendable after running. Bunji et al. (2021) designed a closed-loop green supply chain in terms of the single-period and single-product manner. The research aimed to elevate the profits of collection centers, distributors, and producers. As well, the study aimed to decline environmental costs. A priority considered for customers is an innovation of this attempt. Obtains results showed a sharp increase in environmental and transportation costs with the increase in the amount of demand. Sun Dong Kim et al. (2021) modeled a mathematical approach to achieve sustainable management of closed-loop supply chains. Minimizing environmental costs and transportation costs along with maximizing social effects are among their innovations. Hence, two mathematical stable and evaluation models have been proposed for the minimization of system costs. Due to the NP-hardness of the model, the genetic approach has been used to solve the model. The results of the solution show the proper function of the developed model in minimizing costs. Diabat et al. (2021) presented a multi-commodity and multi-period model in a closed-loop supply chain under uncertainties. The considered goods possess various qualities and recovery is done based on these qualities. Also, there is a special penalty for each backtracking. The considered goals include minimizing the chain costs along with minimizing the environmental impacts. The sensitivity analysis showed that with the increase in demand, the amount of transportation costs elevate greatly. Dong and colleagues (2021) presented a mathematical solution for the management of a closed-loop supply chain in terms of reproduction system and stochastic demand. The model was proposed with three goals, which include: 1- Detection of the producers with the best profit channel. 2- Assignation of a distributor to customer 3- Exploration of the flow between the supply chain levels. Their outcomes indicated an increase in transportation costs with exponential elevation in the entire system cost. Meisam Mehri Charvadeh et al. (2022) have worked on a multi-objective, mathematical model with five levels. In this research, the cost of transportation and establishment of distributions are considered. Considering the costs, results show in a recession scenario four centers, and in a boom scenario, five centers should be established. Parik et al. (2022) presented a comparative analysis of the main Metaheuristics (according to recent surveys) for a sustainable supply chain model. The considered techniques are genetic algorithm, particle swarm optimization, simulated annealing, and non-dominated sorted genetic algorithm. Moreover, two hybrid models are also included, i.e., genetic algorithm combined with simulated annealing and genetic algorithm combined with particle swarm optimization. Asadi et al. (2022) investigated the closed-loop supply chain network design problem considering the environmental and responsiveness features. For this purpose, a multi-objective mathematical model is suggested that minimizes the carbon emissions and the total costs and maximizes the responsiveness of the system. Mohammadi and Nikzad (2022) designed a mathematical model for sustainable closed-loop supply chains during the coronavirus (COVID-19) outbreak. The proposed multi-objective model minimizes the total cost, carbon emission, and infection risk of the network and also maximizes social benefits. Hejazi and Khorshidvand (2023) presented a novel decentralized decision support system to optimally design a general global closed-loop supply chain. This is done through an original risk-based robust mixed-integer linear programming that is formulated based on an initial uncertain bi-level programming. Ghalandari et al. (2023) designed a hybrid model for the robust design of a sustainable closed-loop supply chain in the lead-acid battery industry. Koval et al. (2023) presented a systematic literature review that seeks to map out the main interrelated topics of the circular economy and sustainability-oriented innovation, describing internal and external factors that need to be considered in the transition to a clean energy future. Key lines of research are identified, and suggestions for future research and for how to facilitate the movement toward a circular economy are provided. This study contributes to an enhancement of the literature by identifying priority areas regarding the circular economy and sustainability-oriented innovation to encourage future research that contributes to sustainability and environmental preservation. In Table 1, the reviewed literature is classified based on the types of the supply chain, parameters, objective functions, and solution methods.

Table 1. Classification of literature

Row	Author	Type of supply chain			Parameters				Uncertainty						Target type											Solution Method	
		Direct	Reverse	Closed loop	Multi-product	Multi-capacity	Quality	Certain	Fuzzy	Probable	Scenario	Demand	Supply	Path	Place	Cost	Location	Flow rate	Inventory	Single purpose	Multi-purpose	Two-level	Minimize cost	Minimize risk	Other purposes	Accurate	Metaheuristic algorithms
1	Pedram et al. (2017)	*	*	*		*		*							*	*	*	*		*			*			*	
12	Yun et al. (2020)			*				*										*			*		*				*
13	Huang et al. (2020)			*	*						*	*	*					*			*		*			*	
14	Rihani et al. (2020)			*		*		*													*		*				*
15	Zhang et al. (2020)			*		*					*	*						*					*			*	
16	Rabbani et al. (2020)			*	*	*			*	*		*			*	*	*				*		*			*	*
17	Khalili Nasr and colleagues (2021)			*		*							*					*			*		*		*	*	
18	Fu Qiang et al. (2021)			*	*	*					*										*		*		*	*	
19	Bunji et al. (2021)					*			*										*	*			*			*	
20	Sun Dong Kim et al (2021)			*		*				*					*	*	*		*	*				*	*		*
21	Diabat et al. (2021)			*			*			*					*	*	*	*			*		*			*	
22	Dong et al. (2021)			*		*				*		*				*		*	*		*		*		*	*	
23	Parik et al. (2022)							*													*						*
24	Asadi et al. (2022)			*				*													*		*	*			*
25	Golpira (2022)			*				*													*					*	
26	Mohammadi and Nikzad (2022)			*				*													*					*	

Row	Author	Type of supply chain			Parameters			Uncertainty				Target type														Solution Method	
		Direct	Reverse	Closed loop	Multi-product	Multi-capacity	Quality	Certain	Fuzzy	Probable	Scenario	Demand	Supply	Path	Place	Cost	Location	Flow rate	Inventory	Single purpose	Multi-purpose	Two-level	Minimize cost	Minimize risk	Other purposes	Accurate	Metaheuristic algorithms
27	Ghalandari et al. (2023)			*					*												*						
28	This research			*	*	*	*				*	*	*		*	*	*	*	*		*		*	*		*	*

2.1. The research gaps

Based on the reviewed investigations and Table 1, the most important research gaps have been identified as follows.

- Dealing with the quality of transported and manufactured products is a fundamental parameter that has been neglected in previous researches.
- Not paying attention to risk and minimizing it in a sustainable closed-loop supply chain is one of the important goals of the presented model.
- Paying attention to different scenarios in the discussion of closed-loop logistics as uncertainty such as recession and boom can bring the problem closer to the real world, which has been neglected in previous research.
- Not addressing the performance of distribution and production centers along with the discussion of multiple products at the same time can bring the model closer to the real world, which has not been considered in previous research.

3. Research method

In this research, we intend to provide a sustainable closed-loop supply chain with the following features. This proposed sustainable supply chain network includes four levels in the forward path (including suppliers, factories, distribution centers, and customers) and four levels in the return path (including collection, disassembly, reproduction, and destruction centers) (Figure 1). This is a multi-period and multi-product model. Also, the facilities can open with different capacities. And customers are divided into two categories of domestic market customers and foreign market customers, which the supply chain can send products to the domestic and foreign markets. In this research, the demand of domestic customers must be satisfied, but the demand of the export market does not have such a characteristic. Therefore, considering the market status and relevant episodes, the model clarifies the optimal rate of sending a product to the domestic or export market. Foreign customers have more profits, but the market share of domestic customers is very important. Therefore, the supply chain seeks to decide on the regulation between the domestic and foreign markets. The uncertainty considered in this research is in the form of a scenario. The considered scenarios are market stagnation and boom. In the market recession scenario, the volume of demand is very low, and accordingly, the supply is proportionate to the demand of the recession period, so that there is no excess supply and storage costs are reduced. In the boom scenario, the demand is very high, and accordingly, the supply is also high. Accordingly, there is a shortage in the boom scenario, while there is no shortage in the recession scenario. Comparing recession and boom scenarios can give decision-makers a good understanding and perspective in different market conditions.

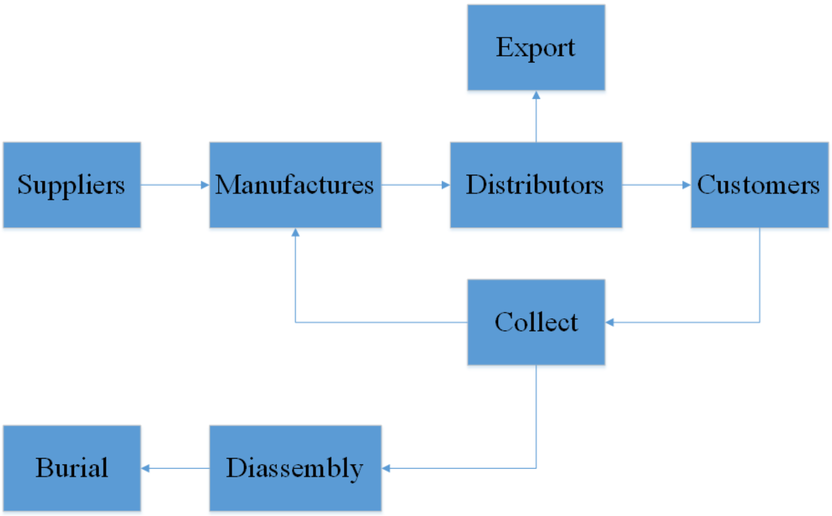

Figure 1. Schematic of the supply chain

In this part of the research, all the steps necessary to carry out the research are introduced. In Figure 2, the flowchart of the implementation steps of the research is shown.

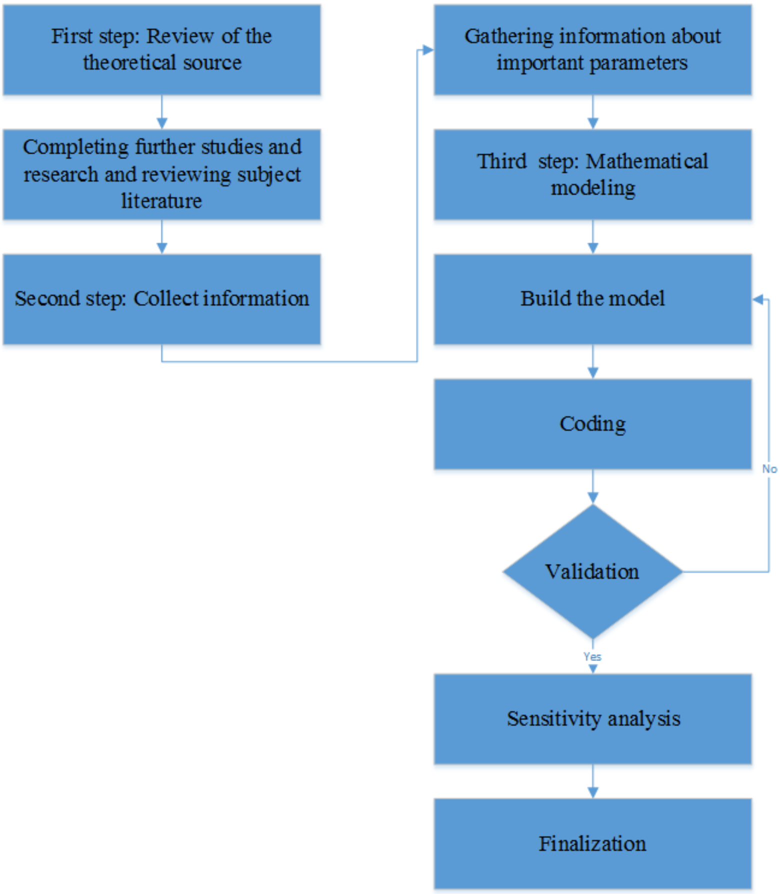

Figure 2. Flowchart of the research method

Also, the most important steps in the implementation of the research are:

Step 1. Examining existing internal and external theoretical sources:

• Completing more studies and research and reviewing the subject literature;

• Detailed examination of the closest studies conducted in this field;

Step 2. Gathering and compiling information:

• Collecting appropriate information about important and influential characteristics and parameters in the problem environment;
• Interviewing the stakeholders of the issue and examining the views effective in solving the issue;
Step 3. Problem modeling:
• Construction and development of a suitable mathematical model by the characteristics and main assumptions of the problem;
• Model coding in a suitable software environment such as GAMS software or any other suitable software;
• Validation of the developed model;
• Sensitivity analysis;
Step 4. Conclusion:
• General summary of research results and suggestions for future research.

3.1.Research assumptions

The most important assumptions that are considered the default for the design and implementation of the mathematical model are:

- Due to the indeterminacy of the demand for final products, which is caused by market fluctuations, the expected demand of the customer is considered indeterminate
- Considering forward and backward transportation networks for products;
- The quality of returned products is considered uncertain;
- Considering different scenarios such as recession and boom in the market situation and product prices;
- Capacity limitations of factories, distribution centers, and warehouses are considered;
- Servicing can be done for each seller through all warehouses and for each warehouse through all distribution centers;

The model is multi-period and multi-product

3.2. Notation

In this section, all symbols used in the paper are described in Table 2.

Table 2. The Current Software Development Environment for Database

Type	Symbol	Description
Set	I	Set of suppliers
	J	A collection of factories
	K	A collection of distributors
	C	The set of customers
	R	Collection of raw materials
	P	Collection of products
	T	Collection of periods
	F	Recycling collection
	S	Scenarios
Index	$i \in I$	The index belongs to the set of suppliers
	$j \in J$	Index belongs to the factories
	$k \in K$	Index belonging to the set of distribution
	$c \in C$	The index belongs to the set of customers
	$r \in R$	Index belonging to the collection of raw materials
	$p \in P$	The index belongs to the collection of products
	$t \in T$	The index belongs to the collection of periods
	$f \in F$	The index belongs to the recycling collection
	$s \in S$	The index belongs to the scenarios

	d_{ckt}	Customer distance from distribution centers at time t
	RR_k	Coverage radius of distribution centers
	λk_{kp}	The amount of manpower required per unit of product p in the distribution center k
	λJ_{jp}	The amount of manpower required per unit of product p in factory j
	Cy_{jkpt}	The cost of the amount of product p that is sent from production center j to distribution center k at time t
	U	The desired number of distributors
	M	A very large number
	D_{cpts}	Customer c's demand product p in period t in scenario s
	Cz_{kcpt}	The cost of the amount of product p that is sent from the distribution center k to the customer c at time t.
	Czz_{fjrt}	The cost of the amount of raw material r sent from recycling center f to factory j at time t.
	Czz'_{kfpt}	The amount of product p is sent from the distribution center k to the recycling center f at time t.
	CIK_{kpt}	Distributor k's inventory cost of product p in period t
	Cbk_{kpt}	Distributor k's shortage cost of product p in period t
Parameters	CIJ_{jpt}	Manufacturer j's inventory cost of product p in period t
	CbJ_{jpt}	The cost of the producer j's shortage of product p in period t
	Cy'_{kt}	Fixed investment cost of distributor k in period t
	β_{kp}	Percentage of p products at manufacturer k that are remanufactured
	$CAPk_{kt}$	Distribution center capacity distributors k in period t
	$CAPJ_{jt}$	The capacity of the factory j in period t
	Q_{kpt}	Product quality value under scenario s at distributor k in period t
	AQ_{kpt}	Average quality accepted product p in distributors k in period t
	α_{rp}	The percentage of conversion of raw material r to product p
	Cx_{ijrt}	The cost of raw material quantity r is sent from a supplier I to manufacturing facility j at time t.
	p_s	The probability of each scenario s
	φ_{jp}	The amount of smoke output per production of product p in producer j
	CIF_{fpt}	Inventory cost of recycling center f of product p in period t
	γ_{fp}	The percentage of products that can be recycled
	y_{jkpts}	The amount of product p that is sent from production center j to distributor center k in scenario s and at time t
	z_{kcpts}	The amount of product p that is sent from the distribution center k to the customer c in scenario s and at time t
	zz_{fjrts}	The amount of raw material r that is sent from recycling center f to factory j in scenarios s and at time t.
	zz'_{kfpts}	The amount of product p is sent from the distribution center k to the recycling center f in scenario s and at time t.
Continuous	IK_{kpts}	Distributor k's inventory of product p in period t in scenario s
	bk_{kpts}	Distributor k's shortage of product p in period t in scenario s
Variables	IJ_{jpts}	Manufacturer j's inventory of product p in period t in scenario s
	bJ_{jpts}	Shortage of producer j of product p in period t in scenario s
	IF_{fpts}	Inventory of recycling center f of product p in period t in scenario s
	x_{ijrts}	The amount of raw material r is sent from supplier i to manufacturing center j in scenarios s and at time t.
Binary	y'_{kt}	If the boundary of distribution k is selected at time t, one, otherwise zero.
	PQ_{kpts}	If product p at distributor k at time t and in scenario s has acceptable quality, the value is one, otherwise it is zero.

3.3. Mathematical model

This section introduces and explains the equations corresponding to the objective functions and the constraints of the problem. For this purpose, first, the objective functions and then the constraints are described.

• Objective functions

In equation (1) the objective functions of costs are shown.

$$A1_s = \sum_{t\in T}\sum_{k\in K}\sum_{p\in P}\sum_{j\in J} y_{jkpts}\,.\,Cy_{jkpt} + \sum_{t\in T}\sum_{k\in K}\sum_{c\in C}\sum_{p\in P} z_{kcpts}.\,Cz_{kcpt} + \sum_{t\in T}\sum_{j\in J}\sum_{f\in F}\sum_{r\in R} zz_{fjrts}.\,Czz_{fjrt} + \sum_{t\in T}\sum_{k\in K}\sum_{f\in F}\sum_{p\in P} zz'_{kfpts}.\,Czz'_{kfpt} + \sum_{i\in I}\sum_{r\in R}\sum_{t\in T}\sum_{j\in J} x_{ijrts}.\,Cx_{ijrt} \quad (1)$$

$$A2_s = \sum_{k\in K}\sum_{p\in P}\sum_{t\in T}(IK_{kpts}.\,CIK_{kpt} + \sum_{c\in C} bk_{kcpts}.\,Cbk_{kcpt}) + \sum_{j\in J}\sum_{p\in P}\sum_{t\in T}(IJ_{jpts}.\,CIJ_{jpt} + bJ_{jpts}.\,CbJ_{jpt}) + \sum_{f\in F}\sum_{p\in P}\sum_{t\in T}(IF_{fpts}.\,CIF_{fpt})$$

$$A3 = \sum_k\sum_t y'_{kt}.\,C\,y'_{kt}$$

The objective function A1S and A2S calculates the cost of sending the goods, the costs of inventory and shortage in the distribution center and the manufacturer, and the cost of inventory in the recycling center, respectively. Also, A3 calculates the fixed cost of the distributor's investment. Considering that all three functions are estimated with the same quantity, we consider the functions related to costs by considering the probability value of each scenario as a coefficient for the objective functions $A1_s$ and $A2_s$ $Min(A) = A3 + \sum_{s\in S} p_s\,(A1_s + A2_s)$. It should be noted that this created function considers the economic dimension of sustainability.
In addition to the costs, in equation (2), the customer coverage objective function of the coverage radius is shown. According to this equation, this objective function seeks to reduce the distance of the customer from the coverage radius of the distribution center to cover the available customers and reduce the risk of customer loss.

$$Min(B) = \sum_{t\in T}\sum_{k\in K}\sum_{c\in C}\frac{d_{ckt}}{RR_k}.\,y'_{kt}$$

In equation 3, the objective function of C1S is in the direction of increasing the employment of people (reducing the unemployment of people), which is calculated based on the amount of input to the distributor for each scenario. Also, the C2S objective function is to increase the employment of people (reduce unemployment of people) which is calculated based on the amount of output in the producer for each scenario. It should be noted that to simplify the number of functions, given that both C1S and C2S functions have the same quantity, by applying the probability to the two considered functions, it will be converted into$Max(C) = \sum_{s\in S} p_s.\,(c1_s + c2_s)$, Function C considers the social aspect of sustainability in the problem.

$$C1_s = \sum_{t\in T}\sum_{k\in K}\sum_{p\in P}\frac{\sum_{j\in J} y_{jkpts}}{\lambda k_{kp}} \quad (3)$$

$$C2_s = \sum_{t\in T}\sum_{J\in J}\sum_{p\in P}\frac{\sum_{k\in K} y_{jkpts}}{\lambda J_{jp}}$$

Finally, function D in equation 4 checks the amount of smoke emitted from the production of product p in the manufacturer based on the amount of product produced according to the defined scenarios. It should be noted that this objective function considers the environmental aspect of the problem.

$$D = \sum_j\sum_k\sum_p\sum_t\sum_s p_s.\,\varphi_{jp} y_{jkpts} \quad (4)$$

• Constraints

The constraints of the problem are shown below.

$$\sum_k y'_{kt} = U \qquad \forall t \in T \quad (5)$$

$$\sum_k z_{kcpts} + \sum_k bk_{kcpts} = D_{cpts} \qquad \forall c \in C, p \in P, s \in S, t \in T \quad (6)$$

$$IK_{kpts} = Ik_{kpst-1} - \sum_{c\in C} z_{kcpts} + \sum_{j\in J} y_{jkpts} - \sum_{f\in F} zz'_{kfpts} \quad \forall k \in K, p \in P, s \in S, t \in T \tag{7}$$

$$\sum_{c\in C} z_{kcpts} + IK_{kpts} \le M.(PQ_{kpts}) \quad \forall k \in K, p \in P, s \in S, t \in T \tag{8}$$

$$\sum_{f\in F} zz'_{kfpts} = \sum_{c\in C} bk_{kcpts} \quad \forall k \in K, p \in P, s \in S, t \in T \tag{9}$$

$$\sum_{c\in C} bk_{kcpts} \le M.(1 - PQ_{kpts}) \quad \forall k \in K, p \in P, s \in S, t \in T \tag{10}$$

$$Ik_{kpts} \le CAPk_{kt} \quad \forall k \in K, p \in P, s \in S, t \in T \tag{11}$$

$$IJ_{jpst} \le CAPJ_{jt} \quad \forall j \in J, p \in P, s \in S, t \in T \tag{12}$$

$$(Q_{kpts} - AQ_{ps}).y'_{kt} \ge (PQ_{kpts}).M \quad \forall k \in K, p \in P, s \in S, t \in T \tag{13}$$

$$(Q_{kpts} - AQ_{ps}).y'_{kt} \le (PQ_{kpts}).M \quad \forall k \in K, p \in P, s \in S, t \in T \tag{14}$$

$$IJ_{jpts} - bJ_{jpts} = IJ_{jpt-1s} + \sum_{r\in R}\sum_{i\in I} x_{ijrts}.\alpha_{rp} - \sum_{k\in K} y_{jkpts} + \sum_{f\in F}\sum_{r\in R} zz_{fjrt-1s}.\alpha_{rp} \quad \forall j \in J, p \in P, s \in S, t \in T \tag{15}$$

$$\sum_{p\in P}(IK_{kpts} + \sum_{c\in C} z_{kcpts}) + \sum_{j\in J}\sum_{p\in P} y_{jkpts} + \sum_{f\in F}\sum_{p\in P} zz'_{kfpts} \le M.y'_{kt} \quad \forall k \in K, s \in S, t \in T \tag{16}$$

$$IF_{fpts} = IF_{fpt-1s} + \gamma_{fp} \sum_{k\in K} zz'_{kfpts} - \sum_{j\in J}\sum_{r\in R} zz_{fjrts}.\alpha_{rp} \quad \forall f \in F, p \in P, s \in S, t \in T \tag{17}$$

Equation (5) specifies the limit of distributor locations. Equation (6) specifies the limit of distributors that fulfill the demand. Equation (7), this constraint determines the balance of the amount of input and output to the distributor, which also determines the amount of inventory, shortage, and sending and receiving in the distributor. Equation (8), if a product is accepted in terms of quality, then we can send the product to the customer or have inventory. Equations (9) and (10), if a product is not accepted in terms of quality, then we will send the product to recycling centers and the customer will have a shortage. Equation (11) specifies this limitation of distributor capacity. Equation (12) specifies this limitation of the producer's capacity. Equations (13) and (14), if the quality of the products is lower than the average accepted quality, then the variable will be equal to zero and it will be sent to the recycling center. Equation (15), this constraint determines the balance of input and output to the factory. In addition to that, the amount of stock, shortage, sending, and receiving is determined. Equation (16), this limitation takes into account the relationship between the location of the selected distributor and other variables. Equation (17), this constraint determines the balance of the amount of input and output in the recycling center, where the amount of inventory, sending, and receiving are determined.

3.4. Solution method

- **Exact solution method**

In the epsilon constraint method, one is selected from among different objective functions and other objective functions are converted into constraints by considering an upper limit, and the problem is converted into a single objective linear programming model and is solved in the usual way of linear programming. to be one of the accurate methods of obtaining optimal Pareto solutions is to use the epsilon constraint approach. The prominent merit of this approach over other multi-objective optimization approaches is utilization for non-convex solution spaces since the approaches like a weighted combination of objectives lose their efficacy in non-convex spaces. The computing time of an algorithm is one of the important features of any algorithm to evaluate it, since one of the main weaknesses of the algorithms based on exact search, including the epsilon method, is the high limitation of their computing time, it is obvious that the use of the meta-heuristic algorithm causes a sharp reduction in the computing time. One of the modified versions of the epsilon constraint method is the framework presented by Pirouz and Khorram (2016) and Abolghasmian et al. (2020) have recommended its use due to its two major properties: minimizing the search space to detect non-dominant points and requiring less execution time than the original protocol. Accordingly, we initially solve the problem of single-objective optimization for each objective. Then, the length of the step is clarified. Next, we form the set of appropriate points and eventually deal with the single objective optimization and determine the Pareto frontier. In this method, one of the objectives is always optimized with the condition of defining the greatest acceptable limit for other objectives in most constraints. For a four-objective problem, we will have the mathematical representation according to equation 18. According to problem, the first objective, which is to minimize the total cost and includes the sum of fixed investment costs, material shipping costs, and inventory and shortage costs, is placed as the main objective in the epsilon constraint problem. The second goal is to minimize the risk of losing customers. The third objective includes maximizing the employment of workers. The fourth objective, which involves minimizing carbon emissions due to distribution activities across the network. They are added to the set of constraints as constraints according to 18 equations.

$$
\begin{aligned}
&\min f_1(x) \\
&s.t \\
&f_2(x) \leq \varepsilon_2 \\
&f_3(x) \geq \varepsilon_3 \\
&f_4(x) \leq \varepsilon_4 \\
&\quad x \in s
\end{aligned}
\tag{18}
$$

By changing the values on the right side of the new constraints of ε, the Pareto frontier of the problem will be obtained.

- **NSGA-II meta-heuristic solution approach**

The NSGA-II algorithm is a potent tool to solve problems, in particular the study problems, involving a huge state space and impossible practically for humans to explore all its modes in high dimensions. As a unique advantage, it should be noted that this algorithm has a high speed in shifting toward solving the problem. Further, unlike several algorithms finding the problem solution space just in a single direction, this algorithm finds the solution in multiple directions at the same time. Another positive trait of this algorithm is the non-continuity and non-convexity of the objective function in the genetic algorithm. The difference between this algorithm and the NSGA algorithm is only in the operation of the selection operator. Due to the complexity of the computational process in this algorithm, Deb and colleagues (2002) developed a more complete NSGA-II algorithm (Deb et al., 2002). The NSGA-II algorithm has the following implementation steps (Pourghader Chobar et al., 2022):

1. Formation of the initial population,
2. Calculation of fitness index,
3. non-dominated sorting of population and computation of crowding distance,
6. Carrying out crossover and mutation to produce new offspring.
7. Integration of primary population with that appeared due to mutation and crossover,
8. Replacement of the parent population with the optimal members of the population integrated into earlier stages. In the first stage, the members of the lower ranks replace the earlier parents and subsequently are sorted based on the crowding distance. The primary population that appeared due to mutation and crossover is initially classified according to their rank, and some of them possessing lower ranks are deleted from the population. In the subsequent stage, the reminder population is classified by the crowding distance, which occurs inside a front. This process is shown in the figure below.
9. All stages are repeated until the targeted generation (or optimal condition).

The proposed chromosomes in this meta-heuristic method are multifaceted. The key operators in such a mutation and intersection approach include two-point intersections applied in this work. In this operator, two points are first chosen randomly and the strings in each chromosome will be swapped.

4. Applied research results

In this part of the research, the findings of the research in Farzan Fan Andish Farda Company, which is among the top knowledge-based companies in Iran and a subset of the knowledge-based institutions of the Amirkabir University of Technology, which is located in Tehran. This company operates in the field of producing electronic components and is considered a case study in this research. Farzan Fan Andish Farda Company (FFAFC) was established in 2014 and is engaged in conducting research studies, production, and commercial engineering design in the field of new energy, electronics and mechatronics and industrial parts, material handling systems and feeding production lines, and export and import of permitted commercial goods and obtains domestic and foreign representation. All research results have been implemented in the deterministic part using GAMS software and in the parametric part using MATLAB software in a system with Intel Core i3 1.8 GHz, 4GB RAM specifications. Tables 4 to 8 show the numerical solution of the problem using the BARON tool in the GAMS software. Before running the model, it is necessary to define the parameters related to the sets considered to solve the model. In this article, according to Table 3, the number of main components related to the supply chain is considered in the FFAFC. In addition, we must first check the feasibility of the problem in a solution space. Table 4 also shows the feasibility of the problem. In this research, to solve the model according to the supply chain components of Company FFAFC shown in Table 3, we assume that two suppliers are used to provide two types of products. The two distributors that exist in Company FFAFC provide different products to customers, which are classified into two categories, internal and external. Waste or defective products are sent to two recycling centers for preparation for reuse, which are located in Tehran and Karaj. In general, we examine the supply chain process of company FFAFC in two scenarios of recession and market boom during two time periods.

Table 3. Determining the amount of the main components of the supply chain in the FFAFC

Name of the components	Number
Supplier	I1, I2
Producer	J1, J2
Distributor	K1, K2
Customer	C1, C2
Products	P1, P2
Recycling centers	F1, F2
Scenario	S1, S2
Period	T1, T2

Taking into account the things mentioned above, the model is implemented to show the feasibility of the problem, and the results of Table 4 are obtained to establish the boundary of feasibility.

Table 4. Boundary of k distribution at time t

Number	First period	Second period
K1	1.00	1.00
K2	1.00	1.00

By receiving the results, the feasibility of a feasible solution is determined for the problem in such a way that it applies within the limits. Assuming the values considered in Table 2, the quantity of product p sent from generation center j to distributor center k in scenario s and at time t in the FFAFC is shown in Table 5.

Table 5. Optimum value $\boldsymbol{y_{jkpts}}$ in the FFAFC

From the towel center to the distribution	Symbol	Scenario	
		Scenario1	Scenario 2
J=1; K=1; P=1	P1.2.1	20	10
J=1; K=2; P=2	P1.1.1	15.276	11.624
	P1.2.2	18.061	19.249
J=2; K=1; P=2	P1.1.2	14.724	11.376
	P2.2.1	10.939	8.751

J=2; K=2; P=1	P1.1.1	35	27
	P1.2.1	15	18

Based on the results obtained in Table 5, the amount of the first product is transferred from the second-generation center to the second distribution center under the first scenario in the FFAFC supply chain. In contrast, the amount of the first product is transferred from the first-generation center to the first distribution center under the second scenario. In Table 5, the amount of product p that is sent from the distribution center k to customer c in scenario s and at time t in the FFAFC is shown.

Table 6. Optimum value z_{kcpts} in the FFAFC

From the distributor center to the customer	Symbol	Scenario	
		Scenario1	Scenario 2
K=1; C=1; P=1	P1.2.1	3.061	8.249
K=2; C=2; P=2	P1.2.2	15	11

Based on the results obtained in Table 6, the highest amount of product transfer from the second distributor to the second customer is related to the first scenario in the FFAFC supply chain. On the other hand, the lowest amount of product transfer from the first distributor to the first customer is done under the first scenario. Based on the results obtained in Table 6, the first customer is less than the second customer under both scenarios. Table 6 shows the number of raw materials r sent from the recycling center f to manufacturer j in scenarios s and at time t in the FFAFC.

Table 7. Optimum value zz_{fjrts} in the FFAFC

From the recycling center to the manufacturer	Symbol	Scenario	
		Scenario 2	Scenario1
F=1; J=1	R1.1	2.501	3.238
	R2.2	2.886	3.608
F=2; J=1	R2.1	0.610	0.802

Based on the results obtained in Table 7, the lowest number of raw materials are transferred from the second recycling center to the first producer, and the highest number of raw materials are transferred from the first recycling center to the first producer for use and reproduction, respectively, for the second scenario and the first scenario. In Table 8, the quantity of product p is sent from supplier center k to recycling center f in scenario s and at time t in the FFAFC. The second product with a value of 31.406 has the highest transfer from the second distribution center to the first recycling center under the first scenario. Meanwhile, the second product under the first scenario is transferred from the second distribution center to the second recycling center with a value of 2.735.

Table 8. Optimum value zz'_{kfpts} in the FFAFC

From the distribution center to the recycling center	Symbol	Scenario	
		Scenario1	Scenario 2
K=1; F=1; P=2	P1.1.1	14.724	11.376
	P1.2.1	10.939	8.751
	P2.2.2	20	10
K=2; F=1; P=2	P2.1.2	31.406	24.265
	P2.2.1	15	18
K=2; F=2; P=2	P2.1.1	15.276	11.624
	P2.2.2	3.594	2.735

In Table 9, the amount of shortage of distributor k of product p in period t in scenario s in the FFAFC is shown. Based on the obtained results, the lowest product shortage in the FFAFC is related to the first product that occurs in the second distributor under the second scenario. In contrast, the largest amount of product shortages related to the second product occurs in the second distributor under the first scenario.

Table 9. Optimum value bk_{kpts} in the FFAFC

Distributor center to customer	Symbol	Scenario	
		Scenario1	Scenario 2
K=1; C=1, P=2	P1.1.1	14.724	11.376
	P1.2.2	10.939	8.751
	P2.2.1	20	10
K=2; C=1; P=2	P1.1.2	3.276	0.624
	P2.1.1	18	16
K=2; C=2; P=2	P1.1.2	12	11
	P2.1.1	17	11
	P2.2.1	15	18

In table 10, the amount of shortage of producer j of product p in period t in scenario s in the FFAFC is shown. Based on the obtained results, the lowest shortage is related to the first producer for the second product in the second scenario. Also, the biggest shortage is related to the second producer, the second product under the first scenario.

Table 10. Optimal value bJ_{jpts} in the FFAFC

Producer	Symbol	Scenario	
		Scenario1	Scenario 2
J=1	P1.1	15.276	11.624
	P1.2	6.745	10.524
	P2.2	7.882	0.665
J=2	P1.1	14.724	11.376
	P1.2	10.939	8.751
	P2.1	35	27
	P2.2	15	18

Finally, the inventory value of recycling center f of product p in period t in scenario s in the FFAFC is shown in Table 11. The highest amount of inventory is related to the second product in the first recycling center under the first scenario. Also, the lowest inventory related to the first product in the second recycling center is the bed of the second scenario.

Table 11. Optimum value IF_{fpts} in the FFAFC

Recycling center	Symbol	Scenario	
		Scenario 2	Scenario1
F=1	P1.1	12	18
	P1.2	17	14
	P2.1	16	18
F=2	P2.2	13	20
	P1.1	11	12
	P1.2	13	15
	P2.1	12	17
	P2.2	18	15

4.1. Meta-heuristic model parameters tuning

In this part of the research, we discuss the calculated results of solving the NSGA-II meta-heuristic method. Before running the model, it is necessary to design several scenarios for the model settings using a test plan to solve it. The Taguchi approach was performed in designing the experiments in the NSGA-II algorithm. Thus, three diverse levels (code 1=low, code 2=medium, code 3=high) are considered for their indices. Then, the pre-determined experiments in this algorithm are implemented for all probable combinations. Table 12 shows the recommended values for the parameters of this algorithm.

Table 12. Parameters and their levels for the NSGA-II algorithm

Parameter	Values of each level		
	Level 3	Level 2	Level 1
Population size (PS)	200	100	50
Crossover rate (CR)	0.9	0.7	0.5
Mutation rate (MR)	0.5	0.3	0.2
Maximum iterations (Max_iter)	200	150	100

Next, various tests were formed by Taguchi's L9 design, and the NSGA-II algorithm was implemented for all (Table 13). As seen, all probable modes are presented for diverse levels regarded for NSGA-II algorithm parameters. For instance, all parameters in the initial test take a part in the experiment based on the minimal level. In the second one, the parameter PS possessing the minimal level value and other parameters possessing their relevant mean average level value is evident. Similarly, other probable modes are completed by the statistical permutation rule. After implementing all the tests and computing the MID values, this index estimates the optimal response level.

Table 12. Response variable values in Taguchi technique for NSGA-II

Execution number	Algorithm parameters				MID index
	PS	CR	MR	Max_iter	
1	1	1	1	1	534.0
2	1	2	2	2	612.0
3	1	3	3	3	537.0
4	2	1	2	3	491.0
5	2	2	3	1	576.0
6	2	3	1	2	637.0
7	3	1	3	2	599.0
8	3	2	1	3	973.0
9	3	3	2	1	642.0

Now, by presenting these outputs to the MINITAB software, the S/N diagram is presented in the form of Figure 3. Based on the calculated signal-to-noise ratio at all levels considered for each of the factors, the lower this value is for the desired level, the value of that level is selected for that factor. As shown in Figure 3, the lowest signal-to-noise ratio in the PS factor occurs when this index is at its high level with code 3. Therefore, the value we consider for this parameter in the NSGA-II algorithm will be equal to 200. Also, the lowest signal-to-noise ratio in the CR index corresponds to the average level with code 2 of this factor. Therefore, the CR factor with a value of 0.7 will be present in the algorithm. In addition, the lowest value for the MR factor corresponds to the time when this factor is at its lowest level with code 1. Therefore, this factor will be present in the algorithm with a value of 0.2. Finally, the Max_iter factor has the lowest value relative to the noise when it is at its high level with code 3. Therefore, this factor will be present in the algorithm with a value of 200.

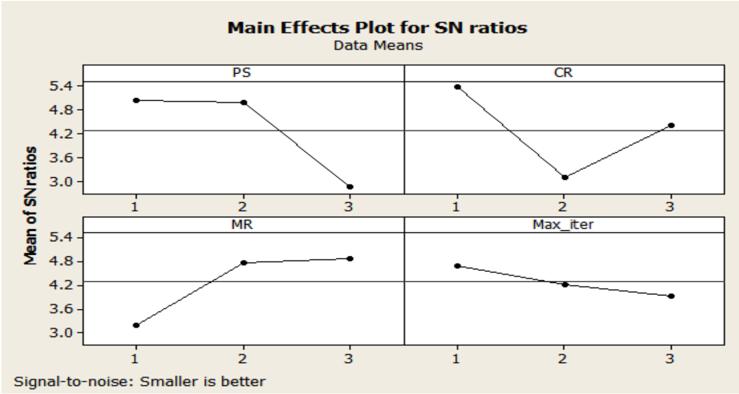

Figure 3. Minitab output for Taguchi method in NSGA-II algorithm

At this time, the output above-mentioned in the diagram is used to specify the optimal value of all parameters (Table 14), and these values of the algorithm parameters are used to implement the other examples. Table 14 shows the best value of the factors.

Table 14. The optimal value of variables in NSGA-II

Parameter	The optimal value
Population size (PS)	200
Crossover rate (CR)	0.7
Mutation rate (MR)	0.2
Maximum iterations (Max_iter)	200

In addition, in figures 4 and 5, the settings related to crossover and mutation are shown. Figure 4 shows the crossover of points in the NSGA-II algorithm. In this operator, two points are first chosen randomly and the strings in each chromosome will be swapped. In Figure 5, the mutation mode in the NSGA-II algorithm for this research is shown. This operator indicates the randomly chosen two points and the reverse of each string in this row.

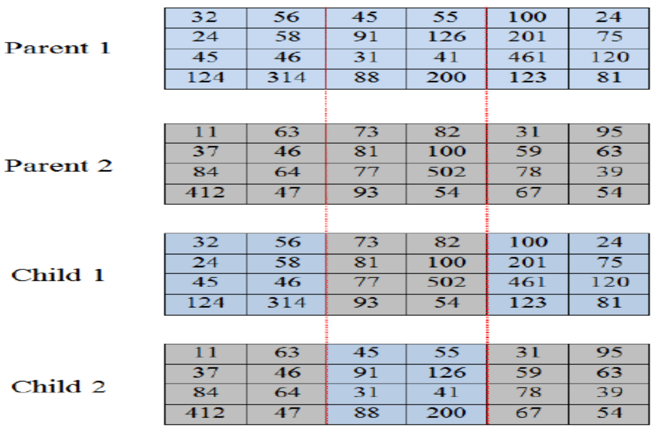

Figure 4. Settings related to crossover operator in NSGA-II algorithm

Parent

81	54	46	62	71	48
6	61	28	95	401	100
47	44	57	401	461	75
100	321	32	63	123	91

Child

81	54	46	62	71	47
100	401	95	28	61	6
47	44	57	401	461	75
100	321	32	63	123	91

Figure 5. Settings related to mutation operator in NSGA-II algorithm

Chromosome encoding in this research is done as a string of binary numbers. Accordingly, each bit in each chromosome strand defines some solution specification. Therefore, any bit string can be a solution but not necessarily optimal. According to the done coding, it provides the possibility of creating different chromosomes in a way that prevents the creation of duplicate chromosomes. In Table 15, a coded chromosome is shown in this research.

Table14. Coded chromosome

1	1	0	1	1	0	1	1	0	1

In Table 14, the findings from the precise solution of the examples produced by GAMS software undergo comparison with the findings from the NSGA-II algorithm based on the two criteria of time and the objective function value. Since the solution time of GAMS software is very high for high-dimensional problems, a time frame of one hour or 3600 seconds is considered for it. If the problem-solving in the GAMS software needs a time greater than one hour, the GAMS software will give a reasonable (not necessarily optimal) solution after reaching the 1-hour time and the execution of the program will be completed. Table 15 summarizes the results of the comparison of solutions with GAMS and NSGA-II software based on the implementation of the experiment in small, medium, and large dimensions based on the comparison with the numbers of distributors, producers, recycling centers, products, and periods. According to the results obtained, it has been determined from the execution of calculations that the mathematical model shows a very favorable ability to solve the problem in small dimensions. This applies even when the number of distributors is assumed to be 3, even though the calculation time increases and of course the dimension of the problem enhances. Because the gap between the deterministic solution results and the meta-heuristic model is reported to be zero percent. But with a further elevation in the number of distributors and the complexity of the problem, while increasing the computing time, the gap between the results also increases to an acceptable extent. To the extent that when the number of distributors is considered equal to 10 to 15, it becomes so difficult to solve the problem for the developed model that it is not able to calculate and solve it. This point is also true regarding the increase in the number of producers, products, recycling centers, and periods. But considering that the gap between the mathematical model and the meta-heuristic model is negligible in small and medium-sized problems, by trusting the results calculated according to the meta-heuristic model, we can rely on the results provided by it to solve large-scale problems.

Table 15. Results of solving sample problems with GAMS and NSGA-II

The dimension of the problem	Issue no	Number of distributors	Number of Manufacturers	Number of products	Number of recycling centers	Number of periods	GAMS		NSGA-II		GAP (%)
							The objective function	solution time (Seconds)	The objective function	solution time (Seconds)	
Small	PR1	1	1	1	1	1	4750	181	4750	73.2	0%
	PR2	2	1	1	1	1	7589	205	7589	98.51	0%
Medium	PR3	3	2	2	2	1	12159	3251	12159	198.654	0%
	PR4	4	2	2	2	1	309658	3505	290325	286.4	6%
	PR5	5	3	4	3	2	401857	3599	400625	431.6	3%

Large	PR6	10	4	5	3	2	-	-	725648	775.9	-
	PR7	15	5	5	3	2	-	-	900367	954.3	-

In Table 15, the value of GAP has been calculated based on the relative absolute error recommended by Abolghasmian et al. (2020) and Jahangiri et al. (2021). According to the corresponding absolute error value, the ratio of the distance between the two outputs of the mathematical and meta-heuristic model compared to the mathematical model is measured according to $\frac{|the\ mathematical\ model - meta\ heuristic|}{mathematical\ model}$ mathematical model-meta heuristic | / (mathematical model). Based on the obtained error value, if it is less than 0.1, the measurement error is acceptable. The average of the obtained errors has been calculated as 0.022, which, considering that it is less than 0.1, the calculation error is within an acceptable limit, and the findings of the meta-heuristic method can be trusted in the long term.

Also, the comparison of the result distance between the first, second, third and fourth objective functions is shown in Figures 6, 7 and 8. Based on the determined solutions, the convergence of the answers is clear and the answers have small distances from each other. Only in the comparison of the first function with the fourth one, the distance between the solutions is slightly greater than the comparison with other objective functions.

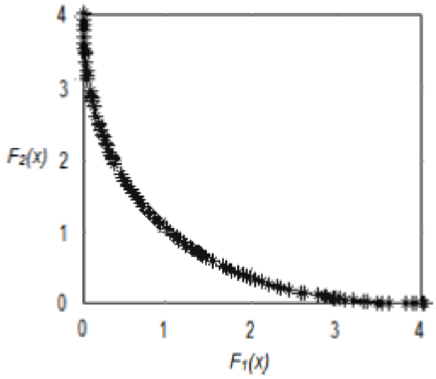

Figure 6. soulution distance between F1(x) and F2(x)

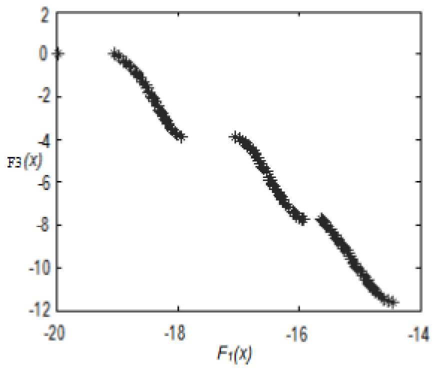

Figure 7. soulution distance between F1(x) and F3(x)

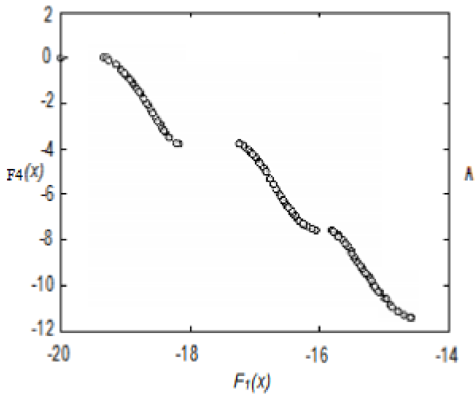

Figure 8. soulution distance between F1(x) and F4(x)

4.2. Sensitivity analysis

In many scientific problems, it is not only important to find the optimal solution of a linear programming problem, but also the number of changes in the optimal solution when the parameters of the problem are changed. The changes in the parameters of a linear programming problem are of two types: discrete and continuous. Studying the separate and continuous effects of parameters on the optimal solution is called sensitivity analysis and parametric analysis, respectively, which is one of the important topics in operational research. In this part, it is necessary to check which parameters the model is sensitive to and shows a significant reaction to its increase and decrease. In this research, the partial scale method is used to clarify the model sensitivity. This method examines the effect of each parameter separately by keeping constant the other factors on the objective function value. In this part of the numerical results, the impact of the important parameter, i.e. the probability of each scenario (recession and prosperity) is investigated. For this purpose, the value of the parameter under both scenarios has been changed between -20% and +20%, and accordingly, the objective function value has been reported. Tables 16 and 17 show the results of the sensitivity analysis of this parameter under two scenarios of recession and boom. According to Table 15, in case of a 20% decrease in the probability of the recession scenario, the objective function value reaches the highest possible value, also, in case of a 20% increase in its value, the objective function value reaches the lowest possible value. In addition, in Table 16, if the value of the probability of the boom scenario decreases by 20%, the objective function reaches the lowest possible value, and if the objective function value elevates by 20%, it reaches the highest possible value. This concept shows that if the recession decreases, which will be followed by an increase in economic prosperity in the case study, the objective function value will increase. Subsequently, if the recession increases, which in this case will lead to a decrease in economic prosperity in the case study, the objective function value will decrease. Therefore, the maximum value of the objective function occurs when the recession decreases, after which the objective function value enhances up to 7398.51 through the creation of a boom. On the other hand, the lowest value of the objective function occurs when the recession increases, and then the objective function value decreases based on the decrease of the boom. Also, in Figures 9 and 10 diagrams of the changes' objective function are depicted.

Table 16. Sensitivity analysis of the probability of recession scenario

Percentage change	20%	10%	0%	-10%	-20%
The value of the objective function	3291.64	6681.49	6107.2	6487.97	9364.35

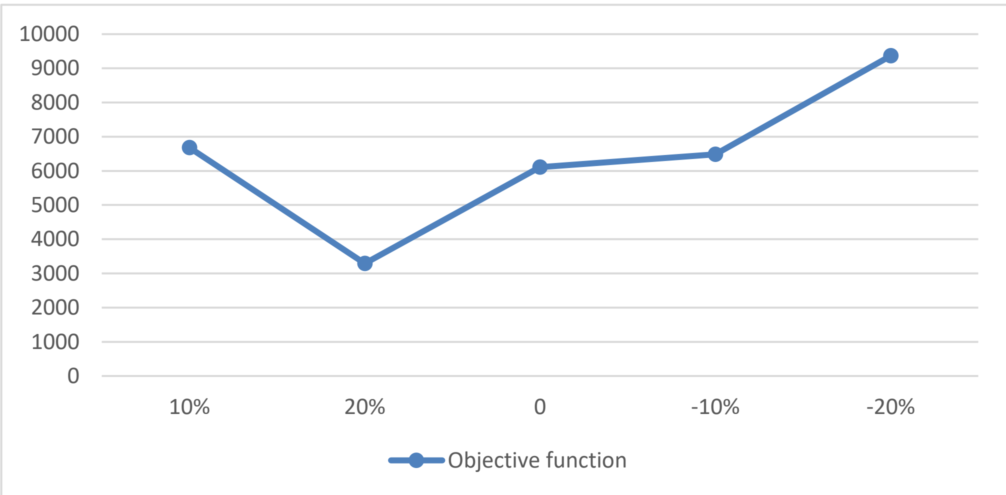

Figure 9. Diagram of changes in the objective function in the recession scenario

Table 17. Sensitivity analysis of the probability of the boom scenario

Percentage change	20%	10%	0%	-10%	-20%

The value of the objective function	7398.51	6897.9	5123.21	3845.95	3245.73

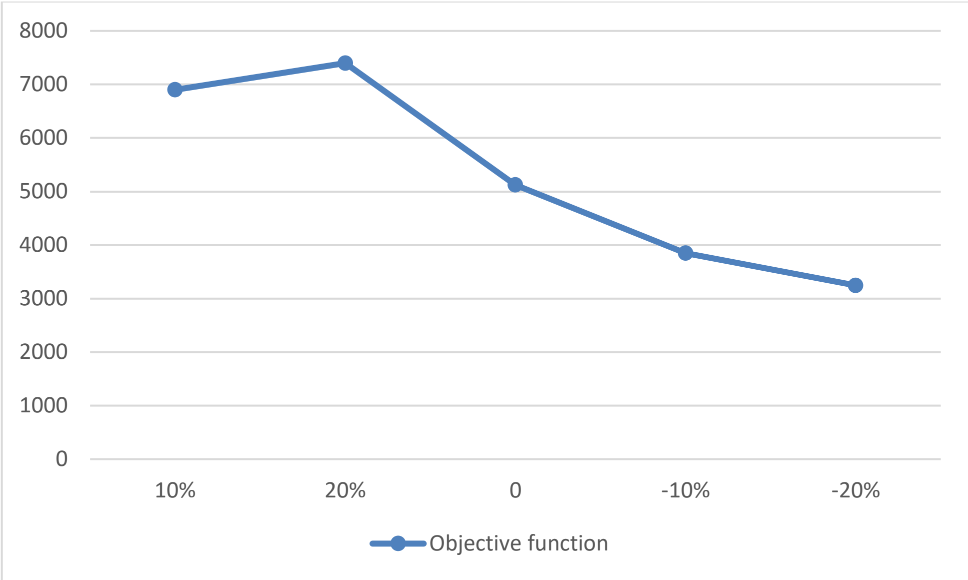

Figure 10. Diagram of changes in the objective function in the boom scenario

5. Conclusions and suggestions

Supply chain management has become an important research area. In addition to these companies, due to the increase in dangerous episodes and relevant effects on the supply chain, they paid further attention to risk management. Given elevated uncertainty in the supply chain, organizations had to consider resources for the prediction of internal uncertainties, demand, and supply of the organization to minimize vulnerability and elevate the resilience of their supply chain. Knowing the uncertainty and the risk factors raised the need to examine risk management in the supply chain. The current work modeled a multi-objective mathematical plan for a sustainable multi-level supply chain, taking into account the conditions of market stagnation and prosperity. Main contribution of current research is reducing the risk of a closed loop supply chain by reducing the risk of establishing new centers and also increasing the distance of establishing new centers from people's places of residence. Simultaneous consideration of economic, environmental, and social responsibility dimensions. Social responsibility is considered as maximizing employment and reducing personnel dismissal. Considering two scenarios of recession and boom to apply supply chain uncertainty to be closer to real state to examine risk reduction and sustainability aspects. Customizing the developed model for a case study on the actual matrix. In the developed supply chain, the collection centers and suppliers in the forward direction provide the components and raw materials for production devices. (Role of the supplier) Depending on the return rate of the products, the demand for components is provided via the collection centers, as a source of supply, by providing enhanced components. If there is a shortage in the provision of enhanced components, factories will procure the required components from suppliers. Distribution centers send new products from factories to customers to provide their demand, and the reverse supply chain process begins when the customer returns. According to the quality, the returned products are separated and the quality components are transferred to the production sectors, the reproducible components are transferred to the reproduction unit and the unusable components are transferred to the destruction section. Quality comes first in the flow of returned products. In this matter, the quality of returned products is considered uncertain. The mathematical programming model developed for the multi-level, multi-cycle, multi-product sustainable supply chain in this research is solved using the BARON tool in GAMS software. The most important practical results from the model solving include:

- The amount of transfer of the type of products from each of the production centers to the distribution centers in different periods has been obtained under recession and boom scenarios. For example, the quantity of the first product is transferred from the second production sector to the second distribution sector under the first scenario. In contrast, the amount of the first product is transferred from the first production sector to the first distribution sector under the second scenario.

- The amount of product transfer from the distributor to the customers has been obtained in each period and under different scenarios. For example, the highest amount of product transfers from the second distributor to the second customer is related to the first scenario. On the other hand, the lowest amount of product transfer from the first distributor to the first customer is done under the first scenario.
- The amount of transfer of raw materials from recycling centers to manufacturers for using materials in re-production has been obtained. For example, the lowest number of raw materials is transferred from the second recycling center to the first producer and the highest amount of raw materials is transferred from the first recycling center to the first producer for use and reproduction, respectively, related to the second scenario and the first scenario.
- The product volume sent from the distribution sector to the recycling sectors to carry out the recovery process in each period and under different scenarios has been determined. For example, the second product with a value of 31.406 has the highest transfer from the second distribution center to the first recycling center under the first scenario. Meanwhile, the second product under the first scenario is sent from the second distribution sector to the second recycling sector with a value of 2.735.
- The amount of shortage of products in each period and under each scenario is specified. For example, the lowest amount of shortage is related to the first producer for the second product in the second scenario. Also, the biggest shortage is related to the second producer, the second product under the first scenario.
- The amount of inventory of products in recycling centers has been obtained in each period and under each scenario. For example, the largest amount of inventory is for the second product in the first recycling center under the first scenario. Also, the lowest inventory related to the first product in the second recycling center is the bed of the second scenario.

Then, the NSGA-II algorithm has been used to show the validity of the suggested mathematical model. Using this algorithm, the capability of the model can be justified in the long run. Because in the problems designed in small and large dimensions, the mathematical model and the algorithm have very little difference in the results. Thus, it is shown how to ensure the results of the meta-heuristic method in the long run. Finally, by performing a sensitivity analysis on the probability parameter of each scenario, we have checked the effect of its change on the objective function. For this purpose, the probability of each scenario has been changed between 20 and -20 percent. The results of the objective function showed that if the probability of a recession scenario decreases, the objective function value increases, and if the probability of a stagnation scenario elevates, the objective function value decreases. Also, if the probability of the boom scenario decreases, the objective function decreases, and if it increases, the objective function increases. Therefore, the main managerial insight of research are as follow:

- Understanding the supply chain risks that companies face allows managers to develop a better ability to recognize and deal with unexpected events. Identification of risks can act as a strategic lever in the competitiveness process of organizations.
- Also, uncertainty and risk in the supply chain have a significant impact on its shape, design, and operation. From another point of view, in any business, due to the existence of risks and uncertainties, if there is no risk in something, it will not have economic value. Because no added value will be created in that activity. Therefore, supply chain risk assessment can protect the business interests and brand of the organization against the basic and important concept of supply chain failure.

Also, the most important limitations of the current research are: the data required for research in this field are complex and voluminous, and institutions that provide these data are needed. Also, conducting research related to multi-objective planning model for multi-level sustainable supply chain may be long and time-consuming. Therefore, you need to be able to devote enough time to this research. For future research, considering that there is uncertainty in the parameters of the presented model, it is recommended to use robust planning in this supply chain or consider a closed-loop supply chain, reverse supply chain, and add lean, agile, and resilience to a problem. Also, strongly recommend that considering uncertain centralized/decentralized production-distribution planning problem in multi-product supply chains and fuzzy mathematical optimization approaches to solve it.

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