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Developing multi-objective mathematical model of sustainable multi-commodity, multi-level closed-loop supply chain network considering disruption risk under uncertainty

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Abstract

Nowadays, the issue of the difference in core competencies has turned into the main factor of competition in the market in most organizations. In line with their operational area, the companies make decisions to further strengthen some of their capabilities, capacities, and specializations. Thus, when an organization concentrates on its strengths and makes efforts for its sustainable development, a competitive advantage evolves in the market. In this regard, the present study proposes a Multi-Objective, Multi-Level, Multi-Commodity, and Multi-Period Closed-Loop Mathematical Model for production, distribution, location, and allocation of the products. The presented model particularly aims to minimize the environmental effects and the total supply chain costs, and to control the social impacts of the supply chain. The present study is mainly innovative in the sense that it considers the quality of the manufactured and transported products, various scenarios in the closed-loop logistics as uncertainty, the capacity of the distribution and production centers, and along with the current multi-commodity discussions, considers the sustainability and resilience in the supply chain, the environmental effects in the model and minimizing the amount of the CO2 emissions. The introduced model was solved in small and medium scales using the Epsilon Constraint approach and in large scales for the case study of Sunny Plast Industries by the Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) approach. The results indicated that as the demand goes up, the costs rise. Costs increase is higher in the Boom Scenario than in the Bust Scenario. Also, with the rise in demands, the number of established centers increases. This increase is faster in the Boom case.

Keywords: Closed-Loop Supply Chain, resilience, sustainability, Boom and Bust

1-Introduction

The growing business competition in the 1990s forced organizations to boost the efficiency in many dimensions of their business (Kouhizadeh et al., 2012). For this reason, industry managers realized that it is not enough only to produce a quality product; rather, they need to supply products considering the customer's desires as to when, where, how, and with their desired quality and cost (Moktadir et al., 2021).

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Under such conditions, the organizations found out they had to manage the units supplying their inputs and the centers related to the delivery and after-sales service support. With such a perspective, supply chain theory and its management evolved. Today, supply chain management (SCM) is set forth as one of the infrastructural foundations worldwide (Sarkar et al., 2021). Besides dealing with the organization and the internal resources, the economic and manufacturing enterprises feel the need to manage and monitor the resources and the related components outside the organization. The reason behind this is to gain a competitive advantage(s) to achieve more market share (Paduloh et al., 2020). Accordingly, operations such as supply and demand planning, material preparation, production and product planning, product maintenance service, inventory control, distribution, delivery, and customer service, previously performed at the company level, are now transferred to the supply chain level (Liu et al., 2021). The key issue in a supply chain is the coordinated management and control of all these operations. SCM performs them so that customers can receive reliable and fast service with quality products at the lowest cost (Dai et al., 2021, Rahmaty et al, 2022).

Due to the changing environment, the change in the way companies interact with distribution centers and suppliers, complexity of markets, reduction in the life of products, and the importance of response time to customers and increasing flexibility, the supply chain is a vital factor for the competitiveness of organizations (Ghasemi et al. 2022). Therefore, recognizing the sustainable supply chain and its implementation will help to improve organization and its performance (Momenitabar et al. 2022). The intensification of the global competition in an ever-changing environment has increased the need for appropriate responses from organizations and industrial companies and their flexibility to deal with the uncertain environment (Safaei et al, 2022, Chobar et al, 2022). Today's organizations, in order to acquire a proper position and maintain it in the national and global markets, require the use of a suitable model such as sustainable supply chain management to achieve the competitive advantage and meet the expectations of customers (Ahmadi and Ghasemi, 2022). Customers in today's organizations are working along with the members of the organization in the production of goods and services, approaches and processes, and the development of knowledge and competitive power (Shafipour-Omrani et al. 2021). Companies and distribution centers have found that their purchasing department can be increasingly effective in increasing their efficiency and effectiveness (Babaeinesami et al. 2022; Rezaei Kallaj et al., 2021), and as a result, they have changed their purchasing patterns and are trying to choose the right way to achieve strategic and purchasing goals (Sohrabi et al. 2021). To accomplish this, appropriate strategic suppliers, distribution centers and manufacturers should be chosen in order to gain competitive advantage with their cooperation. Therefore, implementing sustainable supply chain management is a fundamental requirement.

Reverse logistics management and Closed-Loop Supply Chains (CLSCs) are the most significant and vital aspects of any business and entail the production, service distribution, and support for any type of product. In the present age of business, when the products' life cycle is shrinking every day, the policies of product return are defined by fast response times and customer services, and there is more emphasis on the management of return, rec-re-shaping, and re-storing the finished goods. Newly enforced government laws and green laws associated with the returning and disposal of electronic waste and other hazardous materials also force senior managers of supply chain logistics and processes to take a closer look at the reverse logistics process and the CLSC (Han & Chen, 2021; Pourghader Chobar et al., 2021a,b).

In addition, today, due to the increasing importance of the environmental standards and the organizations' efforts to recycle, effectively and efficiently use the manufactured products, and support the consumers regarding the governmental laws and social responsibility, developing return supply chain and sustainable closed-loop is particularly stressed (Chkanikova & Sroufe, 2021, Jahangiri et al. 2021). Moreover, political issues, demand fluctuations, technological changes, financial instabilities, and natural disasters lead to increasing uncertainty and risks in the supply chain and the formation of supply chain risk management (Negri et al., 201). Many studies have surveyed sustainable supply chains, but the concept of sustainability practices in SC capacity to withstand disruptions has remained untouched (Hosseini et al., 2019). Disruption management involves identifying and assessing the disruption risks, making and implementing disruption risk management decisions, and monitoring the disruption risks (Zavala et al., 2020; Maadanpour Safari et al., 2021). Resilience as a descriptive concept gives an insight into the dynamic properties of environmental and economic systems. Resilience in the supply chain can be defined as the supply chain capacity to resist disruptions and maintain performance and the primary structure when facing disruptions (Emenike & Falcone, 2020; Khalili-Damghani et al., 2021). A resilient supply chain may not be the least expensive one, but a is able to overcome uncertainties and disruptions in the business environment (Shirazi et al., 2021). The competitive advantage of the supply chain does not depend only on low costs, high quality, reduced latency, and a high level of service. Rather, it is related to the ability of the chain to avoid disasters and overcome critical situations, and this is the resilience of the supply chain (Goodarzian et al., 2021a,c). In this respect, overlooking the quality of the products manufactured and transferred as a basic parameter in the previous studies, failure to consider different scenarios in the discussions of the Closed-Loop logistics as uncertainty, ignoring the capacity of the distribution and production centers along with a simultaneous discussion on multi-commodity, neglecting the environmental impacts in the model and minimizing the amount of the emitted carbon dioxide, not paying attention to uncertainty in the demand parameter and not simultaneously considering sustainability and resilience in the supply chain can be mentioned as the main research gaps in this area.

Therefore, the main innovations of the present study are as follows:

1. Considering the quality of the manufactured and transported products;
2. Considering various scenarios in the closed-loop logistics as uncertainty;
3. Considering the capacity of the distribution and production centers along with multi-commodity discussions;
4. Considering sustainability and resilience in the supply chain;
5. Considering the environmental effects in the model and minimizing the amount of the CO2 emissions; and
6. Considering uncertainty in the demand parameter.

In this regard, the main questions of this study are formulated as follows:

1. How can sustainability and resilience be considered simultaneously in the proposed supply chain?
2. How can different market scenarios be considered in a Boom-and-Bust condition?

This article is organized into six sections. The first and second sections present the introduction and literature review. The third and fourth sections provide the problem statement and the mathematical model. The fifth section introduces the solution approaches. The sixth section presents the computational results, and the seventh section is devoted to the conclusion.

2-Literature review

Kumar et al. (2022) have presented a mathematical model for the production, routing and inventory control of perishable products. The proposed supply chain includes suppliers, factories, distributors and customers. The considered innovation is product pricing and paying attention to the amount of carbon release. The proposed model is solved using machine learning approach. Ramadhan et al. (2022) presented a multi-objective mathematical model for routing and locating sales centers. Maximizing profit, minimizing energy consumption along with maximizing job opportunities are among the goals of their research. The proposed model is solved for a real case study and the results show the proper performance of the proposed model. Torabzadeh et al. (2022) presented a transportation model for the management of perishable products. The considered uncertainty is fuzzy. Considering sustainability is one of their research innovations.

Nasr et al. (2021) presented a fuzzy multi-objective model for minimizing the costs in the Closed-Loop Supply Chain. The proposed bi-level model dealt with selecting the suppliers and allocating them to the manufacturers. The major goal of the study was to minimize the environmental costs, operational costs, and lost demand and to maximize employment. Wu (2021) designed the dynamic competitive game in the CLSC, considering the government intervention in the proposed supply chain as the research innovation. Thus, the government has proposed six different strategies for chain management, for which the Nash equilibrium approach was used. The main goal the study pursued was to minimize the environmental costs. The results indicated that the proposed model performed appropriately in minimizing the proposed supply chain costs. Fu et al. (2021) investigated CLSC under uncertainty, in which one of the measures was analyzing the interactions between the forward and reverse supply chain. The question chain included manufacturers, distributors, and retailers. The study mainly targeted maximizing the profit of the CLSC network accompanied by reducing the environmental costs. A series of numerical examples of different sizes suggested the satisfactory performance of the proposed model after being implemented. Li et al. (2021) developed a green CLSC considering single-commodity and single-period cases. The main goals were to maximize the profit of the manufacturers, distributors, and collection centers and minimize the environmental costs. Considering customer preference is one of the main innovations of this study. The results implied that as the demand quantity increases, the environmental and transportation costs rise sharply. Savaskan et al. (2021) surveyed a mathematical model for sustainable CLSC management, where minimizing the environmental and transportation costs and maximizing the social impacts can be mentioned as the study innovations. Thus, two mathematical models, namely, the sustainable and evaluation models, were suggested to minimize system costs. Since the model was NP-hard, a genetic approach was used to solve the model. According to the results, the proposed model performed well in cost minimization. Goodarzian et al. (2021b) presented a sustainable production–distribution–inventory–allocation–location problem in the sustainable medical supply chain network. They considered the distribution of medicines of COVID-19 patients and the periods of production. Three algorithms, namely, ant colony optimization, fish swarm algorithm, and firefly algorithm, were presented to solve the model. Goodarzian et al. (2021d) presented a green medicine supply chain network under uncertainty. They integrated the allocation, location, production, distribution, routing, inventory, and purchasing decisions. Then, two new algorithms, hybrid Firefly Algorithm and Simulated Annealing and Hybrid Firefly Algorithm, were proposed to solve the model. Diabat et al. (2021) presented a multi-product, multi-period model in CLSC under uncertainty. The intended goods were of different qualities, and recovery was done based on the question of quality. Also, there was take-back legislation. The aims were to minimize the CLSC costs and lower the environmental costs. The sensitivity analysis results showed that transportation costs rise sharply by increasing demand. Son et al. (2021) proposed a mathematical model for CLSC considering the random demand and remanufacturing system, where the model targeted three goals, i.e., 1) Determining the manufacturers with the highest profit channel, 2) Allocating distributors to customers, and 3) Investigating the flow between supply chain levels. The results of the intended case study displayed that as transportation costs increase, the whole system's costs increase exponentially.

Yun et al. (2020) designed a resilient CLSC with environmental standards, where the goals were minimizing the total costs, minimizing the total amount of CO_2 emission during production and transportation of products, and maximizing the social impacts. Three types of distribution channels as normal delivery, direct delivery, and direct shipment were considered in this research. Finally, the model was solved with a hybrid genetic algorithm. Tsao et al. (2020) presented a sustainable mathematical programming model for supply chain management under uncertainty, which was considered fuzzy. The location of the facilities and distribution centers were the decisions made in their research. The major goal was to maximize the social benefits and minimize the environmental factors and costs.

Ghomi-Avili et al. (2018) proposed a bi-objective, bi-level fuzzy demand pricing model for Green competitive CLSC design network design in the presence of random disruptions in the suppliers. Environmental issues resulted in studying two strategies: adding reverse flow to the supply chain and controlling CO_2 emissions. The proposed model outlined outsourcing strategies and pricing decisions that maximized profits under competitive conditions and diminished CO_2 emissions through production processes. Jabbarzadeh et al. (2018) presented a hybrid model for sustainable supply chain design performing resiliently in the face of random disruptions, by which they stated a stochastic bi-objective optimization model using the fuzzy c-means clustering method to quantify and evaluate the sustainability performance of the suppliers. The proposed model determined outsourcing decisions and resilience strategies that minimized the expected total costs and maximized the overall sustainability performance in disruptions. Table 1 summarizes the literature on the related supply chain.

Table 1. Literature review

NO	Authors	Decision Type		Feature of model			Type of model							Type of Problem					Type of Commodities		Example		Type of supply chain					Solution procedure		
		Reverse SC	Close loop SC	Product quality	Sustainability	Resilience	Deterministic	Fuzzy	Stochastic	Scenario-based	Robust optimization	Bi-level	Multi-objective	Location	Allocation	Routing	Inventory	Single	Multi	Numerical Example	Case Study	Multi echelon	Multi-period	Risk of supply chain	Manufacturing Tech	Capacitated supply chain	Exact	heuristic	Metaheuristic
1	Jabbarzadeh et al. (2018)		*		*			*	*				*	*				*		*			*					*	
2	Ghomi-Avili et al. (2018)	*						*				*		*			*	*			*		*		*				*
3	Tsao et al. (2020)		*		*		*						*	*					*	*		*				*	*		
4	Yun et al. (2020)		*			*	*						*		*	*					*		*		*				*
5	Son et al. (2021)		*						*				*	*		*			*	*		*							*
6	Diabat et al. (2021)		*			*				*			*			*					*	*	*						*
7	Goodarzian et al. (2021d)		*			*				*				*			*	*		*	*					*		*	
8	Goodarzian et al. (2021b)		*			*				*				*			*	*	*		*					*		*	
9	Savaskan et al. (2021)		*			*			*				*	*			*				*		*						*
10	Li et al. (2021)		*		*					*	*		*	*			*				*	*							*
11	Fu et al. (2021)		*		*					*				*	*				*		*	*					*		*
12	Nasr et al. (2021)		*						*			*		*	*					*		*							*
13	Kumar et al. (2022)	*			*			*				*	*	*		*	*	*			*		*		*				
14	Ramadhan et al. (2022)		*		*					*	*		*	*		*	*				*	*							*
15	Torabzadeh et al. (2022)		*			*				*			*			*					*	*	*				*		
16	**This Paper**		*	*	*	*		*		*			*	*			*		*		*	*	*	*	*	*	*		*

According to the literature review, the research gaps are as follows:

1. Overlooking the quality of the manufactured and transported products as a basic parameter in the previous studies;
2. Overlooking various scenarios in the closed-loop logistics as uncertainty;
3. Failure to pay attention to the capacity of the distribution and production centers along with multi-commodity discussion concurrently;
4. Disregarding the environmental effects in the model and minimizing the amount of the CO2 emissions;
5. Ignoring uncertainty in demand parameter; and
6. Not simultaneously considering sustainability and resilience in the supply chain.

3-Problem statement

The present study is a network design of a multi-level, multi-product, and multi-period sustainable closed-loop supply chain. It simultaneously considers manufacturing and distribution-related disruption in the supply chain, taking the risk of returned products into account. The network in question encompasses various markets, collection centers, production centers, distribution centers, suppliers, recycling and disposal sites. Moreover, by investigating the production process level, the efforts have to be directed towards developing a cleaner production process and reducing the by-product manufacturing, which is detrimental to the environment and human health. Process technologies have to be designed and operationalized to easily register reusable products and lower the use of natural resources.

In line with the discussions on the importance of disruptions in the supply chain, distributors-based disruptions were considered in this study. In this regard, the example of the drivers' strike can be mentioned. It is also viable to focus on the economic sanctions and their impact on the manufacturers, as these disruptions can cause manufacturers to lose part of their production capacity and human resources, and as a result, they will not be able to respond to the customers' requirements in a timely manner. Consequently, it disrupts the supply chain, affecting the whole chain. A variety of factors, including the obsolete technology used in the industries, utilizing substandard raw materials and defective tools, failure to pay attention to the market requirements, inadequate supply, importing low-quality machinery and lines, have seriously damaged the industry. Thus, the present study surveyed the production technology in the production centers where the technologies accessible for the products in the facilities have their own costs. In the proposed CLSC network, it is of great importance to locate the production and distribution centers considering the customers and the best possible flow in the network. The total chain costs, including the fixed reopening costs of the facilities, the total costs of purchase, production, transportation, etc. were taken into account, and the effect of the returned products' risk, the impact of cost risk on each returned product considering resilience strategy in reverse logistics and, the social impacts were considered as the risk of facility establishment in sparsely-populated regions. That is, densely-populated areas consider the establishment of facilities more feasible. It is worth noting that the data are real and have fuzzy uncertainty in demand. Moreover, in case of disruption in the supply and production centers, the disruption repair groups would be dispatched to the disruption site, which would also incur costs to the supply chain, making the supply chain more resilient. In addition, the scenarios were considered as the Boom and Bust cycle in the market, and the model behavior was analyzed in two cases. In the market Bust Scenario, the demand volume is very low, and accordingly, supply is proportional to the demand during the recession when there is no excess supply, and warehousing costs decline. In the Boom scenario, the demand is very high, and thus, the supply is high. Comparing the Boom and Bust scenarios can allow the decision-makers to develop a befitting perception and perspective under various market conditions.

4-Mathematical modeling

4-1-Model assumptions

1. The demand parameter is considered fuzzy.
2. The quality uncertainty is considered in the returned products.

3. The model is multi-product, multi-period, multi-objective with various manufacturing technologies.
4. The location of the potential centers is for establishing fixed facilities, and the model selects the desired center out of the potential sites.
5. The transfer cost between the centers in each scenario is considered fixed.

Indices

l	Customers $l \in L$
b	Recycling centers $b \in B$
d	Distributors $d \in D$
c	Products $c \in C$
g	Collection centers $g \in G$
e	Burial and disposal sites $e \in E$
n	Suppliers $n \in N$
m	Manufacturers $m \in M$
t	Period $t \in T$
q	The quality of products $q_1, q_2, ..., Q$
v	Product manufacturing technology $v \in V$
s	Scenarios $s \in S$
f	Repair group f

Parameters:

lin	Capacity of center n
li'_{mv}	Capacity of center m for reconstructing products with technology v
li_e	Capacity of center e
li_{mv}	Capacity of center m with technology v
li_g	Capacity of center g
li_b	Capacity of center b
li_d	Capacity of center d
cb'''_e	Emitted CO2 amount for establishing center e
cb'_g	Emitted CO2 amount for establishing center g
cb''_b	Emitted CO2 amount for establishing center b
cb_d	Emitted CO2 amount for establishing center d
cpk	Emitted CO2 amount from delivering a unit of good per distance unit
h'''_d	Establishment cost of center e
h''_p	Establishment cost of center p
h'_g	Establishment cost of center g
h_d	Establishment cost of center d
vl_{cs}	Value of product c in scenario s after recycling
$\widetilde{d_{ls}^{ct}}$	Demand for product c by customer l in period t in scenario s
fo_{cs}	Manufacturing cost of a unit of product c in scenario s
$f'o_{cs}$	Collection cost of a unit of product c in scenario s
$pg^s{}_{cq}$	Price of returned product c with quality q in scenario s
d_{gmvqs}^c	Transfer distance/ cost of product c from center g to center m with quality q by technology v in scenario s
d_{nms}^c	Transfer distance /cost of product c from center n to center m in scenario s
d_{mds}^c	Transfer distance/ cost of product c from center m to center d in scenario s
d_{lgs}^c	Transfer distance/ cost of product c from customer l to center g in scenario s

d_{gbqs}^{c}	Transfer distance/ cost of product c from center g to center b with quality q in scenario s
d_{geqs}^{c}	Transfer distance /cost of product c from center g to center e with quality q in scenario s
d_{bmqs}^{c}	Transfer distance/ cost of product c from center b to center m with quality q in scenario s
d_{dls}^{c}	Transfer distance/ cost of product c from center d to customer l in scenario s
pr_s	Chances of scenario s occurrence
$r_{l,q,s}^{ct}$	Return rate of product c with quality q from customer site l during period t in scenario s
rr'^{ct}	Return rate of product c from collection center to burial site during period t
rr^{ct}	Return rate of product c from collection center to the manufacturer during period t
rr''^{ct}	Return rate of product c from collection center to recycling center during period t
pol_{dt}	Total emitted pollution in establishment flow of center d during period t
pol'_{gt}	Total emitted pollution in establishment flow of center g during period t
pol''_{bt}	Total emitted pollution in establishment flow of center b during period t
pol'''_{et}	Total emitted pollution in establishment flow of center e during period t
α_{mts}	If no disruption occurs in manufacturing center m during period t in scenario s, it's 1; otherwise, 0
β_{nts}	If no disruption occurs in supply center n during period t in scenario s, it's 1; otherwise, 0
cm_{mts}	Repair cost of manufacturing center m during period t in scenario s
cm'_{nts}	Repair cost of supply center m during period t in scenario s

Variables:

x_d	If center d is established, it's 1; otherwise, 0
x'_g	If center g is established, it's 1; otherwise, 0
x''_b	If center b is established, it's 1; otherwise, 0
x'''_e	If center e is established, it's 1; otherwise, 0
z_{gmvqs}^{ct}	Number of product c sent from center g to center m by technology v with quality q during period t in scenario s
z_{mvds}^{ct}	Number of product c sent from center m to center d by technology v during period t in scenario s
z_{dls}^{ct}	Number of product c sent from center d to customer l during period t in scenario s
z_{bmqs}^{ct}	Number of product c sent from customer l to center g with quality q during period t in scenario s
z_{geqs}^{ct}	Number of product c sent from center g to center e with quality q during period t in scenario s
z_{nms}^{ct}	Number of product c sent from center n to center m during period t in scenario s
z_{gbqs}^{ct}	Number of product c sent from center g to center b with quality q during period t in scenario s
y_{mt}	If repair group f is sent to center m during period t, it's 1
y'_{nt}	If repair group f is sent to center n during period t, it's 1

$$Min\, f_1 = (\sum_{d\in D} h_d x_d + \sum_{g\in G} h'_g x'_g + \sum_{b\in B} h''_b x''_b + \sum_{e\in E} h'''_e x'''_e) + pr_s(\sum_t \sum_s (\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} \beta_{mts}.\, d_{nms}^{c} z_{nms}^{ct} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx_{jks}^{st} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d_{dl,s}^{c} z_{dls}^{ct} \qquad (1)$$

$$+\sum_{s\in S}\sum_{t\in T}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^{c}_{lgs} z^{ct}_{lgs} + \sum_{v\in V}\sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^{c}_{gmqs} z^{ct}_{gmvqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^{c}_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^{c}_{geqs} z^{ct}_{geqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^{c}_{bmqs}\, z^{ct}_{bmqs}\right)$$

$$+\sum_{v\in V}\sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} \alpha_{mts}.fo_{\ cs}\,.z^{ct}_{mvds}$$

$$+\sum_{t\in T}\sum_{s\in S}\sum_{c\in C}\sum_{d\in D}\sum_{m\in M} f'o_{cs}\left(\left(\sum_{g\in G}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{g\in G}\sum_{e\in E} z^{ct}_{geqs} + \sum_{v\in V}\sum_{g\in G}\sum_{m\in M} z^{ct}_{gmvqs}\right)\right)$$

$$+\sum_{m\in M}\sum_{s\in S}\sum_{t\in T} y_{mt}.cm_{mts} + \sum_{n\in N}\sum_{s\in S}\sum_{t\in T} y'_{nt}.cm'_{nts}$$

$$Min\, f_2 = LM + LP \tag{2}$$

$$LM = \sum_{b\in B} x''_{b}.\ cb''_{b} + \sum_{g\in G} x_{g}.\ cb'_{g} + \sum_{e\in E} x'''_{e}.\ cb'''_{e} + \sum_{d\in D} x_{d}.\ cb_{d} \tag{3}$$

$$LP = \sum_{s\in S} w_{sen}.\sum_{t\in T} CEM\left[\sum_{t}\sum_{s}\left(\sum_{c\in C}\sum_{n\in N}\sum_{m\in M} d^{c}_{nms} z^{ct}_{nms} + \sum_{c\in C}\sum_{n\in N}\sum_{d\in D} mdx^{st}_{jks} + \sum_{c\in C}\sum_{d\in D}\sum_{l\in L} d^{c}_{dl,s} z^{ct}_{dls} + \sum_{s\in S}\left(\sum_{c\in C}\sum_{l\in L}\sum_{m\in M} d^{c}_{lgs} z^{ct}_{lgs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{b\in B} d^{c}_{gbqs} z^{ct}_{gbqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{e\in E} d^{c}_{geqs} z^{ct}_{geqs} + \sum_{v\in V}\sum_{c\in C}\sum_{q\in Q}\sum_{g\in G}\sum_{m\in M} d^{c}_{gmqs} z^{ct}_{gmvqs} + \sum_{c\in C}\sum_{q\in Q}\sum_{b\in B}\sum_{m\in M} d^{c}_{bmqs}\, z^{ct}_{bmqs}\right)\right)\right] \tag{4}$$

$$Minf3 = \sum_{t\in T}\sum_{d\in D} pol_{dt}.x_{d} + \sum_{g\in G}\sum_{t\in T} pol'_{gt}\ .x'_{g} + \sum_{b\in B}\sum_{t\in T} pol''_{bt}\,.x''_{b} + \sum_{e\in E}\sum_{t\in T} pol'''_{et}.x'''_{e} \tag{5}$$

Subject to:

$$\sum_{e\in E} x'''_{e} \geq 1 \tag{6}$$

$$\sum_{g\in G} x'_{g} \geq 1 \tag{7}$$

$$\sum_{d\in D} x_{d} \geq 1 \tag{8}$$

$$\sum_{b\in B} x''_b \geq 1 \tag{9}$$

$$\sum_{q_2}\sum_{n\in N} z^{ct}_{gbqs} = rr''^{ct} \sum_{q}(\sum_{l\in L} z^{ct}_{lgqs}) \quad \forall g\in G, c\in C, t\in T, s\in S \tag{10}$$

$$\sum_{g\in G} z^{ct}_{lgqs} = r^{c}_{lqs}.\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls} \quad \forall l\in L, d\in D, t\in T, q\in Q, s\in S \tag{11}$$

$$\sum_{q1}\sum_{m\in M} \alpha_{mts}.z^{ct}_{gmvqs} = rr^{ct}\sum_{q}(\sum_{l\in L} z^{ct}_{lgqs}) \quad \forall g\in G, v\in V, c\in C, t\in T, s\in S \tag{12}$$

$$\sum_{m\in M}(\alpha_{mts}.z^{ct}_{mvds} + w^{ct}_{mds}) = \sum_{l\in L} z^{ct}_{dls} \quad \forall d\in D, v\in V, c\in C, t\in T, s\in S \tag{13}$$

$$\sum_{q2}\sum_{e\in E} z^{ct}_{geqs} = rr'^{ct}\sum_{q}(\sum_{l\in L} z^{ct}_{lgqs}) \quad \forall c\in C, t\in T, g\in G, s\in S \tag{14}$$

$$\sum_{q_2}\sum_{g\in G} z^{ct}_{gbqs} = \sum_{q}\sum_{m\in M} z^{ct}_{bmqs} \quad \forall b\in B, c\in C, t\in T, s\in S \tag{15}$$

$$\sum_{q_1}\sum_{m\in M}\alpha_{mts}.z^{ct}_{gmvqs} + \sum_{q_2}\sum_{b\in B} z^{ct}_{gbqs} + \sum_{q_3}\sum_{e\in E} z^{ct}_{geqs} = \sum_{q}\sum_{l\in L} z^{ct}_{lgqs} \tag{16}$$

$$\sum_{n\in N} z^{ct}_{nms} + \sum_{q_1}\sum_{g\in G}\alpha_{mts}.z^{ct}_{gmvqs} + \sum_{q\in Q}\sum_{b\in B} z^{ct}_{bmqs} = \sum_{d\in D}\alpha_{mts}.z^{ct}_{mvds} \quad \forall m\in M, v\in V, c\in C, t\in T, s\in S \tag{17}$$

$$rr^{ct} + rr'^{ct} + rr''^{ct} = 1 \quad \forall c\in C, t\in T \tag{18}$$

$$\sum_{d\in D} z^{ct}_{dls} = d^{ct}_{ls} \quad \forall l\in L, c\in C, t\in T, s\in S \tag{19}$$

$$\sum_{c\in C}\sum_{m\in M} z^{ct}_{nms} \leq li_n \quad \forall n\in N, t\in T, s\in S \tag{20}$$

$$\sum_{c\in C}\sum_{d\in D} z^{ct}_{mvds} \leq li_{mv} \quad \forall m\in M, v\in V, t\in T, s\in S \tag{21}$$

$$\sum_{c\in C}\sum_{l\in L} z^{ct}_{dls} \leq li_d x_d \quad \forall d\in D, t\in T, s\in S \tag{22}$$

$$\sum_{q_3}\sum_{c\in C}\sum_{g\in G} z^{ct}_{geqs} \leq li_e x'''_e \quad \forall e\in E, t\in T, s\in S \tag{23}$$

$$\sum_{c\in C}(\sum_{q_1}\sum_{g\in G}\alpha_{mts}.z^{ct}_{gmvqs} + \sum_{q}\sum_{b\in B} z^{ct}_{bmqs}) \leq li'_{mv} \quad \forall m\in M, v\in V, t\in T, s\in S \tag{24}$$

$$\sum_{qs_2}\sum_{c\in C}\sum_{g\in G} z^{ct}_{gbqs} \leq li_b x''_b \quad \forall b\in B, t\in T, s\in S \tag{25}$$

$$\sum_{q_1}\sum_{c\in C}\sum_{g\in G}\alpha_{mts}.z^{ct}_{gmvqs} + \sum_{q_3}\sum_{c\in C}\sum_{e\in E} z^{ct}_{geqs} + \sum_{q_2}\sum_{c\in C}\sum_{b\in B} z^{ct}_{gbqs} \leq li_g\, x'_g \quad \forall g\in G, v\in V, t\in T, s\in S \tag{26}$$

$$1-\alpha_{mts} \leq y_{mt} \quad \forall m\in M, t\in T, s\in S \tag{27}$$

$$1-\beta_{nts} \leq y'_{nt} \qquad \forall n \in N, t \in T, s \in S \qquad (28)$$

$$z_{gmvqs}^{ct}, z_{mvds}^{ct}, z_{dls}^{ct}, z_{bmqs}^{ct}, z_{lgqs}^{ct}, z_{geqs}^{ct}, z_{nms}^{ct}, z_{gbqs}^{ct} \geq 0 \qquad (29)$$

$$x_d, x'_g, x''_b, x'''_e, y_{mt}, y'_{nt} \in \{1,0\} \qquad \forall d \in D, g \in G, b \in B, e \in E \qquad (30)$$

The objective function (1) minimizes the cost of establishment, flow of commodities, transfer, the cost of products returns, burial costs, collection, and production. The objective functions (3-4) consist of two parts, including minimizing the adverse effects of CO2 induced through the establishment of centers and transfer. The objective function (5) minimizes the risks. In fact, the model will make efforts to establish the facilities in the areas having a lower risk of pollution and population. This objective function was employed consistent with social responsibility.

Constraint (6) indicates that at least one burial site is established. Constraint (7) denotes that at least one collection center is established. Constraint (8) states that at least one distribution center is established. Constraint (9) implies that at least one recycling center is established. Constraint (10) shows the balance between the collection and recycling centers. Constraint (11) indicates that all returned products must be collected from the customers. Constraint (12) displays the balance between the collection and production centers. Constraint (13) represents the number of goods sent to the customer. Constraint (14) displays the balance between the collection and burial sites. Constraint (15) shows the balance of the recycling node. Constraint (16) displays the number of goods sent from the customer to the collection centers. Constraint (17) indicates the number of goods sent from the manufacturer to the distributor.

Constraint (18) states that the sum of the returned products coefficients equals 1. Constraint (19) indicates that the demand has to be fully met. Constraint (20) displays the capacity of the suppliers. Constraint (21) shows the capacity of the manufacturers. Constraint (22) depicts the capacity of the distributors. Constraint (23) guarantees that a burial site can be used if that site has been established. Constraint (24) demonstrates the manufacturing center's capacity to recycle the products. Constraint (25) ensures that a recycling center can be used if that center has been established. Constraint (26) shows the collection centers. Moreover, a collection center can be used if that center has been established. Constraints (27 & 28) imply that if a center breaks down, it has to be reconstructed by the repair group. Constraints (29 & 30) stand for the type of decision variables.

The approach utilized in this research for fuzzification of the approach was that of Tan and Cao (2005). A triangular fuzzy approach was employed in this study concerning the existing uncertainty in the demand and the feasibility of dividing demand in a triplet. Since the demand parameter was considered fuzzy, it is defined as:

$(\widetilde{d_1, d_2, d_3})_{ls}{}^{ct}$	The fuzzy demand of product *c* by customer *I* during period *t* in scenario *s*

Now consider solving a classical linear mathematical model as follows:

$$\begin{aligned} &\text{Max } C^t x \\ &\text{Subject to:} \\ &\quad A_i x \leq b_i \qquad (i = 1, \ldots, m) \\ &\quad x \geq 0 \end{aligned} \qquad (30)$$

Where A, B, and c are definite numbers. A fuzzy constraint is transformed into a definite membership function in this approach. Considering the objective function as the following, Tan and Cao define the linear normal fuzzy model as follows:

LP (α)

$$MaxC^t x$$

Subject to:

$$A_i x \leq b_i + (1-\alpha)p_i \quad , \quad i = 1,2,\ldots,m \quad , \quad x \geq 0 \quad , \quad \alpha \in [0,1]$$

$\alpha \in [0,1]$ is a parameter. Also, $pi \geq 0$, which is called the linear-term coefficient. x_α is the optimal value of the model LP_α. B_α and z_α are the optimal vector and the optimal solution of the equation LP_α.The right coefficient of the model is defined as $b + (1-\alpha)p$, which varies based on the value of α. P0 is the optimal and secondary vector difference.

Now select z1 as the optimal value of LP_1 and z_0 as the optimal value of LP_0, where $p_0 = z_0 - z_1 > 0$. Thus, the proposed algorithm is summarized into the following steps:

Step 1: Solve the linear models (LP_1) and (LP_0). Put their optimal values as x_1 and x_0. Put the optimal coefficients matrix as B_0 for LP_0.

Step 2: Solve the equation $[B_0^{-1}(b + (1-\alpha)p]_i = 0$. Take the solution as equation (32).

$$\alpha_1, \dots, \alpha_{n-1}, (0 < \alpha_1 < \cdots < \alpha_{n-1} < 1) \tag{32}$$

$$\text{Let } \alpha_0 = 0,\ \alpha_n = 1, \alpha = \alpha_1, k = 1 \tag{33}$$

Step 3: Solve equation LPa.

Assume the optimal value as z_a. If $z_1 + p_0\alpha$, go to step 4; otherwise$k = k + 1, \alpha = \alpha_k$ and return to step 3.

Step 4: Find the optimal value of alpha.

$$\alpha{*}{=}\frac{z_1.\alpha_k - z_1.\alpha_{k-1} - z_{\alpha_{k-1}}.\alpha_k + z_{\alpha_k}.\alpha_{k-1}}{z_{\alpha_k} - z_{\alpha_{k-1}} - \alpha_k.p_0 + \alpha_{k-1}.p_0}$$

Step 5: Solve equation LPa and find the optimal solution of $x_{\alpha*}$ and the optimal value of $z_{\alpha*}$. Take Constraint *C* with range *x* in which $c_\alpha = \{x | x \in X, C(x) \geq \alpha\}$. The value of the fuzzy objective function is $z_\alpha = z_1 + p_0.\alpha$ and $z_\alpha = C_{B\alpha}.B_\alpha^{-1}(b + (1-\alpha)p)$.

5-Solution approaches

5-1- Epsilon constraint method

The Epsilon constraint method is one of the most accurate methods for solving multi-objective programming, which overcomes some of the convexity problems of the total weight method, which is the most basic method for solving such problems. This method involves optimizing one main objective function (f_p) and expressing other objectives in the form of unequal constraints.

The basic form of the epsilon constraint is as follows:

$$\min_{x \in \Omega} F_p(x)$$
$$subject\ to$$
$$F_i(x) \leq \varepsilon_i \qquad i = 1, \dots, m \quad i \neq p$$

The steps of the Epsilon Constraint method are as follows (Javadi et al., 2020):

1. Select one of the objective functions as the main objective function.
2. Solve the problems each time considering one of the objective functions and find the optimal values of each objective function.
3. Divide the interval between the two optimal values of the auxiliary objective functions into a predetermined number and find a table of values for $\varepsilon_{2\dots}$, ε_n.
4. Each time, solve the problem with the main objective function with each of the values $\varepsilon_{2,}\dots$, εn.
5. Report the discovered Pareto solutions.
6. By applying changes on the right-side values of the constraints (εi), find the efficient solutions to the problem.

5-2-Non-Dominated Sorting Genetic Algorithm-II (NSGA-II)

The improved Non-Dominated Sorting Genetic Algorithm- II (NSGA-II) is one of the most popular and widely applied optimization algorithms in multi-objective optimization. This algorithm was developed by Deb in 2002 (Sun et al., 2018). First, the initial parent population, *P*, is created. The population is sorted according to the sorting algorithm, and each individual is assigned a Pareto front rank. At this point, the multi-optimization problem is converted into a simple Pareto Front utility function optimization problem. The binary tournament selection operators, the crossover, and the mutations are employed to create the children population as Q with N children. From this generation onwards, the method works differently due to applying the elitism process in which initially, a hybrid population of the parents and offspring is formed. Then, the hybrid population is sorted based on the comparison operator, and N better individuals out of it are considered the next generation population as $Pt + 1$. Subsequently, via N-population $Pt + 1$ and the selection, reproduction, and mutation operators, the N-population Qt+1 is created.

5-2-1- Chromosome definition

Various chromosomes have been represented for defining decision variables. Here, for instance, the variables y_{mt} *and* y'_{nt} as 1 if the repair group *f* is dispatched to center *m* during period *t* and 1 if the repair group *f* is sent to the center *n* during period *t*, are defined as the following. The rows stand for the manufacturers and the suppliers, and the columns represent the time period. The numbers within each gene also indicate the dispatching or not dispatching the group (figure 1)

	t_1	t_2	t_3	t_1	t_2	t_3
m_1	1	1	0	0	0	1
m_2	0	0	1	1	0	1
n_1	1	1	0	1	0	1
n_2	0	1	1	1	1	0

Fig.1: Chromosome representation

5-2-2- Search mechanism

For crossover operation, primarily, out of the sorted population, the parent has to be selected proportionate to the crossover rate, for which the roulette wheel mechanism is used, so that among the set of solutions, it is more probable to select higher ranks and within a set of solutions, the chances of selecting the solutions with higher congestion distance are higher.

5-2-3-Crossover

Crossover operation is carried out as a single-point based on location variable. This selection mechanism leads to the focused solutions and the algorithm's convergence. A two-point crossover was utilized in the current study, where two points were randomly selected in the chromosome and swapped.

Parent 1	32	56	45	55	100	24
	24	58	91	126	201	75
	45	46	31	41	461	120
	124	314	88	200	123	81
Parent 2	11	63	73	82	31	95
	37	46	81	100	59	63
	84	64	77	502	78	39
	412	47	93	54	67	54
Child 1	32	56	73	82	100	24
	24	58	81	100	201	75
	45	46	77	502	461	120
	124	314	93	54	123	81
Child 2	11	63	45	55	31	95
	37	46	91	126	59	63
	84	64	31	41	78	39
	412	47	88	200	67	54

Fig.2. Crossover operator

5-2-4-Mutation

For performing mutation, a chromosome is randomly selected. In fact, random selection leads to increasing the diversity of the solutions. The mutation is performed based on the location variable as a percentage of the chromosome's length. In this study, a line of chromosomes is randomly selected and inverted to mutate.

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

Fig.3. Mutation operator

Tuning the parameters performed in the current study is reported based on the Taguchi approach as the following (table 2):

Table 2: Tuning the Parameters

Parameters	Description	Value
nPop	Population number	100
MaxIt	Iteration number	100
Pc	Cross over rate	0.8
Pm	Mutation rate	0.4

5-3- Comparative standards of multi-objective algorithms' efficiency

There are various standards for analyzing the presented algorithm's efficiency, detailed below:

1- The average distance index from the Mean Ideal Distance (MID) point:
In the following term, n equals the number of Pareto points, and $f_{1,total}^{max}$ and $f_{1,total}^{min}$ are respectively the maximum and the minimum values of the objective function among all of the study algorithm's objective functions.

$$MID = \frac{\sum_{i=1}^{n} \sqrt{\left(\frac{f_{1i}-f_1^{best}}{f_{1,total}^{max}-f_{1,total}^{min}}\right)^2 + \left(\frac{f_{2i}-f_2^{best}}{f_{2,toal}^{max}-f_{2,total}^{min}}\right)^2}}{n} \quad (34)$$

In the above relation, the ideal point's coordinates are (f_1^{best}, f_2^{best}).

2- Space Uniformity Index or Spacing:
This index evaluates the solutions existing in the Pareto front, and it is calculated as the following:

$$SM = \frac{\sqrt{\frac{\sum_{i=1}^{n}(d_i-\bar{d})^2}{n}}}{\bar{d}} \quad (35)$$

In the term mentioned above, n stands for the number of the Pareto solutions and d_i for the Euclidean distance between the two-side Pareto solutions in the solution space. Also, $\bar{d}$ is equal to the average distances of $d_i s$. . The small value of this standard indicates the more uniform solution distribution in the identified Pareto.

6-Computational results

This section provides numerical examples to prove the proposed mathematical model's proper performance. Table (3) presents the numerical problems' scales. As it can be seen clearly, 8 numerical problems exit. Problems 1-4 display the small scales, and 5-8 are of the medium scales. The larger the problem gets in scale, the problem nodes get more in number. For instance, in the first example, the number of burial sites, collection centers, manufacturing centers, recycling sites, customers, distribution, and suppliers is equal to 1.

Table 3. Sizes of numerical problems

Scale	Samples	Disposal centers	Collection centers	Manufacturers	Recycling centers	Customers	Distribution centers	Supplier
Small	Sample1	1	2	1	1	1	1	1
	Sample2	2	2	2	2	1	2	2
	Sample3	2	2	3	2	1	2	3
	Sample4	2	3	3	2	1	3	3
Medium	Sample5	3	3	3	3	2	3	3
	Sample6	3	3	4	3	2	3	4
	Sample7	4	4	4	3	2	3	4
	Sample8	4	4	4	4	2	4	4

Table (4) displays the small- and medium-sized model solution results. The first four are for the small scales, and the second four are for the large scales. As seen, the model was solved using epsilon constraint and non-dominated sorting approaches, and the results are reported as the following. Besides, the solution time period is reported. The solution time period of the Epsilon constraint approach increases exponentially, while the non-dominated sorting solution time periods increase at a lower rate. Moreover, the non-dominated sorting approach error is below 1% in all cases. Thus, the results obtained through this approach can be relied on for solving large-scale problems.

Table 4. Comparative results for solving small- and medium-sized problems

No	Epsilon constraint				NSGA-II				Error%		
	f_1	f_2	f_3	Time(s)	f_1	f_2	f_3	Time(s)	f_1	$\boldsymbol{f_2}$	$\boldsymbol{f_3}$
1	509	289.4	3.46	1	509	289.4	3.46	1	0	0	0.00
2	541	300.2	4.74	37	542	300.2	4.77	5	0.001	0	0.62
3	649	302.1	5.36	49	650	303.3	5.37	6	0.001	0.003	0.18
4	691	320.3	6.01	99	693	321.9	6.03	14	0.008	0.005	0.33
5	1454	629	6.65	1021	1457	631.6	6.69	27	0.002	0.004	0.59
6	1568	737.5	7.2	1413	1572	740.4	7.25	34	0.002	0.003	0.68
7	1600	804.6	7.98	2934	1604	806.3	7.99	39	0.002	0.003	0.12
8	1909	983.3	8.1	7371	1911	987.6	8.19	63	0.001	0.003	0.09

Table 5 demonstrates the evaluation standards of the NSGA-II approach's performance. As perceived, the average MID standard equals 6.04, and the average SM equals 0. 148. Therefore, the results achieved by the proposed solution approach can be trusted for solving the problems of large scale (the case study).

Table 5. Performance evaluation standards

MID	SM
0	0
6.48	0.06
6.68	0.10
6.69	0.12
6.73	0.18
6.68	0.16
6.77	0.26
6.75	0.19
6.84	0.21
6.87	0.21

Figure 4 depicts the solution time period of the small-and-medium-sized instances. As observed, the solution time period of the Epsilon constraint approach increases exponentially, while that of the NSGA-II approach is highly lower than that of the exact solution approach.

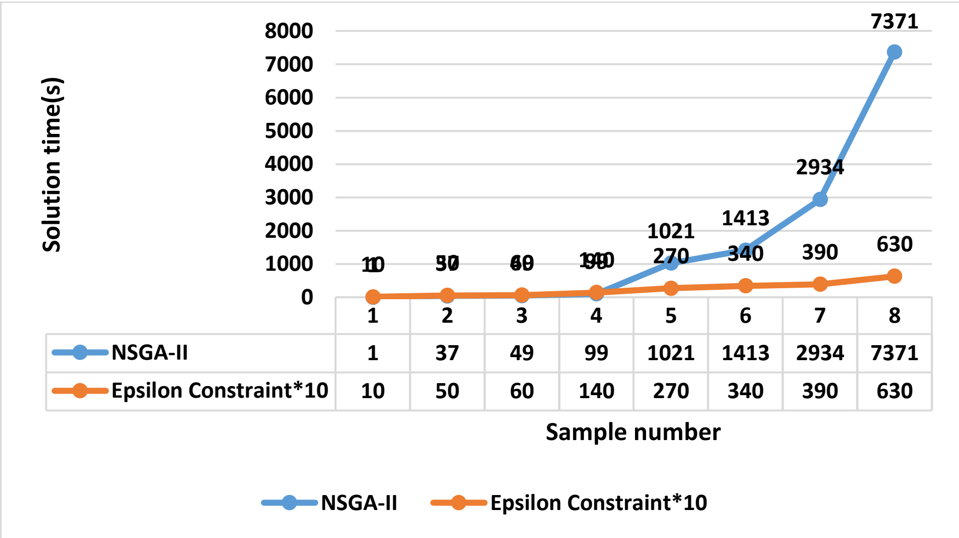

Fig.4. Comparing Two Proposed Approaches' Solution Time Period

6-1- Case study

The case study of the present research is Sunny Plast Industries, which is a mass plastic products manufacturer s made up of five suppliers, four products, five distributors, six collection centers and 15 major customers. Consequently, the final products like nylon and paper bags will be delivered to the customers after collecting the raw materials. Next, the waste is collected from the customers and sorted according to their quality. Some are buried and some are recycled and remanufactured. The present study mainly pursued the goal of minimizing the environmental effects and controlling the social impacts. In addition, in case of disruption in the supply and production centers, disruption repair groups will be sent to the disruption site, which also incurs a cost to the supply chain that in turn makes the supply chain more resilient.

Table 6. Establishment costs of potential centers in case study

Distribution center	**D1**	**D2**	**D3**	**D4**	**D5**		
Establishment cost	50000	30000	50000	25000	40000		
Collection center	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	
Establishment cost	30000	30000	30000	20000	30000	40000	
Recycling center	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
Establishment cost	30000	25000	30000	35000	30000	20000	20000	**25000**
Disposal center	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	
Establishment cost	60000	50000	60000	40000	40000	50000	50000	

6-1-1- Case study results

Figure 5 demonstrates the Pareto points resulting from solving the case study. As indicated, since the proposed model is three-objective, the Pareto points are displayed three-dimensionally.

Table 6 shows the case study performance evaluation standards. As observed, the average MID performance standard for the case study is 6.53, and for the SM, it is 0.22.

Table 7 gives the mathematical model's solution output for the case study. These tables display the values of the product flow from the supply centers to the manufacturing centers in each scenario and each period. As seen, the flow in Scenario 1 (Boom Scenario) is more than that of Scenario 2 (Bust Scenario). For example, the commodity flow sent from Supply Center 1 to Manufacturing Center 1 in the Bust scenario in Period 2 equals 112 units of the commodity.

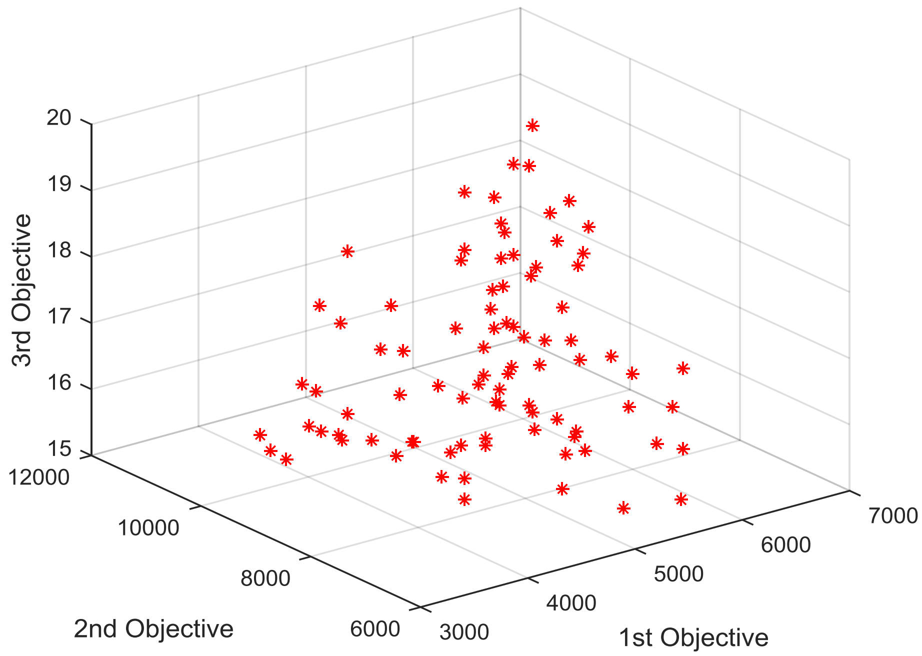

Fig.5. Case study Pareto points

Table 7. Case study performance evaluation standards

MID	SM
6.43	0.08
6.44	0.09
6.70	0.19
6.75	0.14
6.79	0.25
6.72	0.16
6.13	0.35
6.11	0.26
6.25	0.25
6.98	0.29

Table 8. Product flow values from supplies to manufacturing centers

Scenario/Period Manufacturer and supplier	Scenario2-Period2	Scenario2-Period1	Scenario1-Period2	Scenario1-Period1
Supplier1 -Manufacturer1	112	167	136	274
Supplier1 –Manufacturer4	698	288	876	574
Supplier2-Manufacturer3	516	435	666	486
Supplier2-Manufacturer2	772	388	1045	574
Supplier3-Manufacturer5	424	236	636	299
Supplier3 –Manufacturer4	913	412	1949	546
Supplier4 -Manufacturer1	558	425	636	568
Supplier4 –Manufacturer4	519	274	656	336
Supplier5 –Manufacturer3	403	742	451	826
Supplier5 –Manufacturer4	407	503	497	686

Also, the results indicate that burial site 6 and collection center 3 will not be established. Figure 6 shows the number of the established recycling centers as the demand rises. Demand increase leads to higher number of the established centers. This issue is faster in boom case. For instance, by 10% demand rise, the number of the established centers increase from 7 to 8 in boom case**.** The reason behind this is the number of the distribution centers and constraint remaining fixed in the number of the established recycling centers.

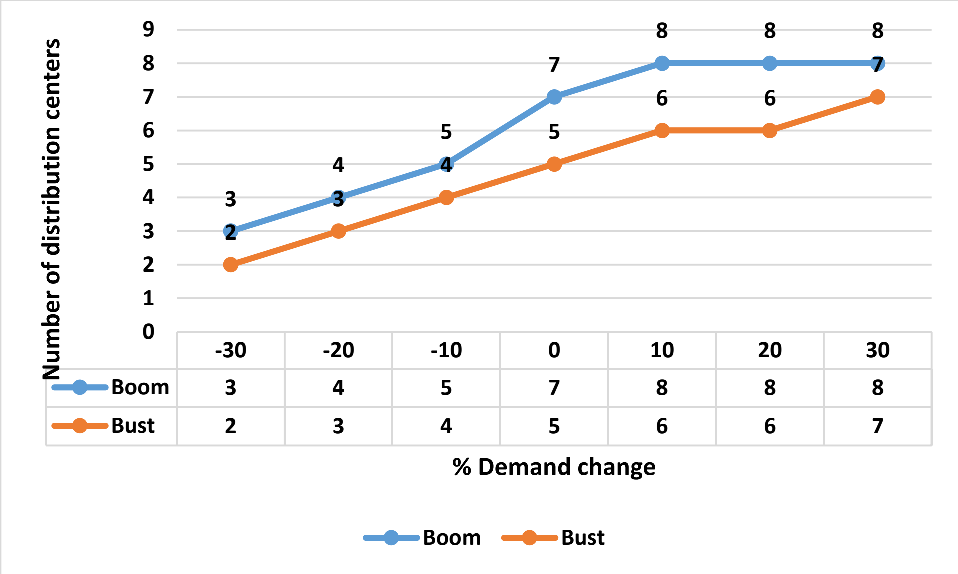

Fig.6. Effect of demand variation on number of established recycling centers

Figure 7 displays that the cost effect varies based on the demand changes. As observed, the demand rise increases the costs. The costs rise in Boom Scenario is higher than that in bust scenario. By 30% demand decline, the costs drop up to 3560 units in Boom Scenario and 1810 units in Bust Scenario. While by 30% demand raise, the costs increase up to 7640 units in boom scenario and up to 6957 units in bust scenario.

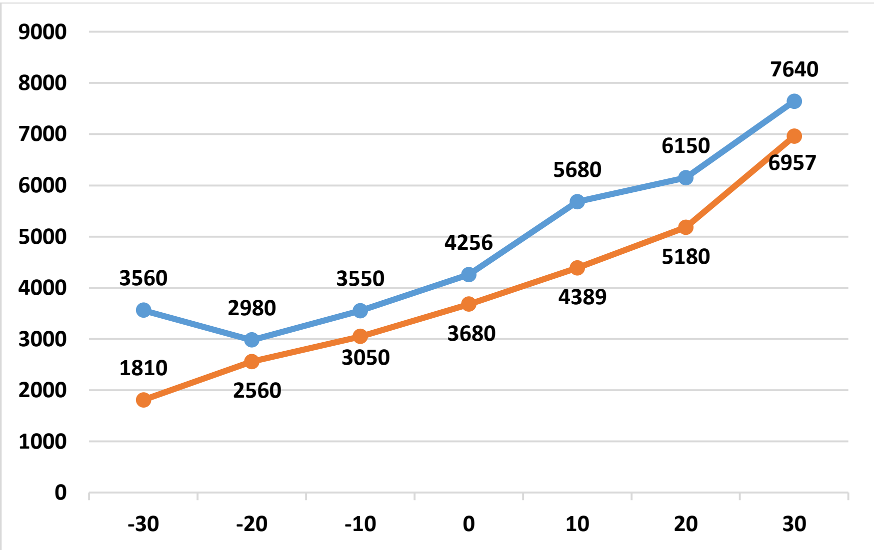

Fig.7. Demand effect on costs

7-Conclusion

All organizations, institutions, bodies, companies and institutions and producers and customers who deal with the purchase, sale, and distribution of all kinds of materials in the supply chain can benefit from the results of the research. such as the National Oil Company, petrochemicals, plastic industries, etc. In order to reduce costs, maximize profit and reduce possible delay fines to deliver materials to customers in order to satisfy customers and the target community. In this research, a model for supply management in the supply chain of plastic materials industry is discussed. Two points can be deduced from this definition. First, risk management in the closed loop supply chain is a set of interconnected decisions and actions. Therefore, this phenomenon has a process nature. Second, risk management is influenced by certain conditions. Therefore, investigating this phenomenon requires attention to the context of its occurrence and emergence in this industry. It should be noted that returned goods should be viewed as a valuable asset. In many companies, such as the German company Bosch, returned goods are seen as valuable assets rather than a waste stream of unusable waste. Given that many components have a limited life cycle and will soon lose their value if not used on time, the company's executives place great emphasis on extracting the maximum possible benefits from the returned goods. Technology can help assess the status of returned goods at the lowest possible cost. Assessing the status of returned goods may lead to long delays and low reverse supply chain speeds. It is better for managers to design a reverse supply chain according to the needs of the organization, the type of products, and the products' life cycle. The life cycle of goods and their products must first be determined. In the current study, a Sustainable Multi-Commodity, Multi-Level and Multi-Period Closed-Loop Supply Chain Network was developed, and disruption in production and distribution in the supply chain regarding the risk of the returned products was analyzed simultaneously. Considering the variety of manufacturing technologies along with fuzzy uncertainty for demand, scenario uncertainty for Boom and Bust cycles and quality uncertainty for the returned products made the model closer to the real world. The study network includes various markets, collection centers, manufacturing centers, distribution centers, suppliers, collection and recycling centers and disposal sites.

The main innovation of the present research is to consider sustainability and resilience in the proposed supply chain concurrently. Thus, the facilities may fail in the supply chain, and after the failure, they can be repaired, and the disruption risk is removed by the relevant groups. Moreover, according to this study, considering the production process level, efforts have to be directed towards developing a cleaner production process and reducing the by-products that may damage the environment and be detrimental to human health. Therefore, the study mainly targets minimizing the supply chain costs and environmental impacts as well as controlling the social effects. As a result, the model was solved in small and medium scales using the Epsilon Constraint and in large scales by the Non-Dominated Sorting Genetic Algorithm-II approach. The case study considered in this research is Sunny Plast Industries. The average MID standard equals 6.04, and the average SM standard equals 0. 148. Also, for the case study, the average MID performance standard is 6.53, and the average SM standard is 0.22. Besides, the flow in the Boom Scenario is more than that in the Bust Scenario. For example, the commodity flow sent from supply chain 1 to manufacturing center 4 in bust scenario in period 2 equals 698 units of the commodity. Besides, the results indicate that burial site 6 and collection center 3 will not be established. As demand increases, the established centers get higher in number, too. This issue is faster in boom scenario.

Of the benefits behind using the proposed meta-heuristic algorithms, we can point out the following:

1. The NSGA-II algorithm use only the values of the objective function to perform the optimization process and do not require additional information such as the function derivative;

2. Due to the simplicity of the search process of NSGA-II, they work very quickly and efficiently;

3. The proposed algorithm (NSGA-II) is very flexible and work with all kinds of objective functions and constraints in the search space.

Also, the disadvantage of the proposed meta-heuristic algorithms is the following: The final solution in NSGA-II algorithm depends on the coder's skill in defining chromosomes and the initial value of its parameters

The presented algorithm's main limitations are summarized as follows: The presented metaheuristic algorithm cannot calculate the global optimum and the local optimum. It also requires access to a computer system equipped with high RAM and CPU features. The following issues are suggested as direction for future studies:

1. Addressing the hybrid meta-heuristic approaches and comparing the meta-heuristic approaches with each other;
2. Investigating other goals such as maximizing the coverage level and routing of the vehicles;
3. Considering a secondary market for selling products of lower quality; and
4. Estimating the demand using approaches like the neural network and fuzzy inference system for the proposed case study.

References

Ahmadi, S. A., & Ghasemi, P. (2022). Pricing strategies for online hotel searching: a fuzzy inference system procedure. Kybernetes, (ahead-of-print).

Babaeinesami, A., Tohidi, H., Ghasemi, P., Goodarzian, F., & Tirkolaee, E. B. (2022). A closed-loop supply chain configuration considering environmental impacts: a self-adaptive NSGA-II algorithm. Applied Intelligence, 1-19.

Chkanikova, O., & Sroufe, R. (2021). Third-party sustainability certifications in food retailing: Certification design from a sustainable supply chain management perspective. Journal of Cleaner Production, 282, 124344.

Chobar, A. P., Adibi, M. A., & Kazemi, A. (2022). Multi-objective hub-spoke network design of perishable tourism products using combination machine learning and meta-heuristic algorithms. *Environment, Development and Sustainability*, 1-28.

Dai, J., Xie, L., & Chu, Z. (2021). Developing sustainable supply chain management: The interplay of institutional pressures and sustainability capabilities. Sustainable Production and Consumption, 28, 254-268.

Diabat, A., & Jebali, A. (2021). Multi-product and multi-period closed loop supply chain network design under take-back legislation. International Journal of Production Economics, 231, 107879.

Emenike, S. N., & Falcone, G. (2020). A review on energy supply chain resilience through optimization. Renewable and Sustainable Energy Reviews, 134, 110088.

Fu, R., Qiang, Q. P., Ke, K., & Huang, Z. (2021). Closed-loop supply chain network with interaction of forward and reverse logistics. Sustainable Production and Consumption, 27, 737-752.

Ghasemi, P., Hemmaty, H., Pourghader Chobar, A., Heidari, M. R., & Keramati, M. (2022). A multi-objective and multi-level model for location-routing problem in the supply chain based on the customer's time window. Journal of Applied Research on Industrial Engineering.

Ghomi-Avili, M., Naeini, S. G. J., Tavakkoli-Moghaddam, R., & Jabbarzadeh, A. (2018). A fuzzy pricing model for a green competitive closed-loop supply chain network design in the presence of disruptions. Journal of Cleaner Production, 188, 425-442.

Han, X., & Chen, Q. (2021). Sustainable supply chain management: Dual sales channel adoption, product portfolio and carbon emissions. Journal of Cleaner Production, 281, 125127.

Hosseini, S., Ivanov, D., & Dolgui, A. (2019). Review of quantitative methods for supply chain resilience analysis. Transportation Research Part E: Logistics and Transportation Review, 125, 285-307.

Jabbarzadeh, A., Fahimnia, B., & Sabouhi, F. (2018). Resilient and sustainable supply chain design: sustainability analysis under disruption risks. International Journal of Production Research, 1-24.

Jahangiri, S., Abolghasemian, M., Ghasemi, P., & Pourghader Chobar, A. (2021). Simulation-based optimization: analysis of the emergency department resources under COVID-19 conditions. International journal of industrial and systems engineering, 1(1), 1504.

Javadi, M., Lotfi, M., Osório, G. J., Ashraf, A., Nezhad, A. E., Gough, M., & Catalão, J. P. (2020, July). A multi-objective model for home energy management system self-scheduling using the epsilon-constraint method. In 2020 IEEE 14th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG) (Vol. 1, pp. 175-180). IEEE.

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. International Journal of Production Economics, 231, 107831.

Kumar, V., Pallathadka, H., Sharma, S. K., Thakar, C. M., Singh, M., & Pallathadka, L. K. (2022). Role of machine learning in green supply chain management and operations management. Materials Today: Proceedings, 51, 2485-2489.

Li, B., Wang, Y., & Wang, Z. (2021). Managing a closed-loop supply chain with take-back legislation and consumer preference for green design. Journal of Cleaner Production, 282, 124481.

Liu, Z., Zheng, X. X., Li, D. F., Liao, C. N., & Sheu, J. B. (2021). A novel cooperative game-based method to coordinate a sustainable supply chain under psychological uncertainty in fairness concerns. Transportation Research Part E: Logistics and Transportation Review, 147, 102237.

Moktadir, M. A., Dwivedi, A., Khan, N. S., Paul, S. K., Khan, S. A., Ahmed, S., & Sultana, R. (2021). Analysis of risk factors in sustainable supply chain management in an emerging economy of leather industry. Journal of Cleaner Production, 283, 124641.

Maadanpour Safari, F., Etebari, F., & Pourghader Chobar, A. (2021). Modelling and optimization of a tri-objective Transportation-Location-Routing Problem considering route reliability: using MOGWO, MOPSO, MOWCA and NSGA-II. Journal of optimization in industrial engineering, 14(2), 83-98.

Momenitabar, M., Dehdari Ebrahimi, Z., Arani, M., Mattson, J., & Ghasemi, P. (2022). Designing a sustainable closed-loop supply chain network considering lateral resupply and backup suppliers using fuzzy inference system. Environment, Development and Sustainability, 1-34.

Nasr, A. K., Tavana, M., Alavi, B., & Mina, H. (2021). A novel fuzzy multi-objective circular supplier selection and order allocation model for sustainable closed-loop supply chains. Journal of Cleaner Production, 287, 124994.

Negri, M., Cagno, E., Colicchia, C., & Sarkis, J. (2021). Integrating sustainability and resilience in the supply chain: A systematic literature review and a research agenda. Business Strategy and the Environment.

Paduloh, P., Djatna, T., Sukardi, S., & Muslich, M. (2020). Uncertainty models in reverse supply chain: A review. International Journal Supply Chain Management, 9(2), 139-149.

Pourghader Chobar, A., Adibi, M. A., & Kazemi, A. (2021). A novel multi-objective model for hub location problem considering dynamic demand and environmental issues. Journal of industrial engineering and management studies, 8(1), 1-31.

Pourghader Chobar, A., Sabk Ara, M., Moradi Pirbalouti, S., Khadem, M., & Bahrami, S. (2021). A multi-objective location-routing problem model for multi-device relief logistics under uncertainty using meta-heuristic algorithm. Journal of Applied Research on Industrial Engineering.

Ramadhan, G. T., Sutopo, W., & Hisjam, M. (2022). A Sustainable Location-Allocation Model for Solar-Powered Pest Control to Increase Rice Productivity. Applied System Innovation, 5(2), 39.

Rahmaty, M., Daneshvar, A., Salahi, F., Ebrahimi, M., & Chobar, A. P. (2022). Customer Churn Modeling via the Grey Wolf Optimizer and Ensemble Neural Networks. Discrete Dynamics in Nature and Society, 2022.

Rezaei Kallaj, M., Abolghasemian, M., Moradi Pirbalouti, S., Sabk Ara, M., & Pourghader Chobar, A. (2021). Vehicle routing problem in relief supply under a crisis condition considering blood types. Mathematical Problems in Engineering, 2021.

Safaei, S., Ghasemi, P., Goodarzian, F., & Momenitabar, M. (2022). Designing a new multi-echelon multi-period closed-loop supply chain network by forecasting demand using time series model: a genetic algorithm. Environmental Science and Pollution Research, 1-15.

Sarkar, B., Sarkar, M., Ganguly, B., & Cárdenas-Barrón, L. E. (2021). Combined effects of carbon emission and production quality improvement for fixed lifetime products in a sustainable supply chain management. International Journal of Production Economics, 231, 107867.

Savaskan, R. C., Bhattacharya, S., & Van Wassenhove, L. N. (2004). Closed-loop supply chain models with product remanufacturing. Management science, 50(2), 239-252.

Shafipour-Omrani, B., Rashidi Komijan, A., Ghasemi, P., Ghasemzadeh, E., & Babaeinesami, A. (2021). A simulation-optimization model for liquefied natural gas transportation considering product variety. International journal of management science and engineering management, 16(4), 279-289.

Sohrabi, R., Pouri, K., Sabk Ara, M., Davoodi, S. M., Afzoon, E., & Pourghader Chobar, A. (2021). Applying sustainable development to economic challenges of small and medium enterprises after implementation of targeted subsidies in Iran. Mathematical Problems in Engineering, 2021.

Son, D., Kim, S., & Jeong, B. (2021). Sustainable part consolidation model for customized products in closed-loop supply chain with additive manufacturing hub. Additive Manufacturing, 37, 101643.

Sun, Y., Lin, F., & Xu, H. (2018). Multi-objective optimization of resource scheduling in Fog computing using an improved NSGA-II. Wireless Personal Communications, 102(2), 1369-1385.

Tan, Y. F., & Cao, B. Y. (2005, August). Another discussion about optimal solution to fuzzy constraints linear programming. In International Conference on Fuzzy Systems and Knowledge Discovery (pp. 156-159). Springer, Berlin, Heidelberg.

Torabzadeh, S. A., Nejati, E., Aghsami, A., & Rabbani, M. (2022). A dynamic multi-objective green supply chain network design for perishable products in uncertain environments, the coffee industry case study. International Journal of Management Science and Engineering Management, 1-18.

Tsao, Y. C., Thanh, V. V., Lu, J. C., & Yu, V. (2018). Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming. Journal of Cleaner Production, 174, 1550-1565.

Wu, C. H. (2021). A dynamic perspective of government intervention in a competitive closed-loop supply chain. European Journal of Operational Research, 294(1), 122-137.

Yun, Y., Chuluunsukh, A., & Gen, M. (2020). Sustainable closed-loop supply chain design problem: A hybrid genetic algorithm approach. Mathematics, 8(1), 84.

Zavala-Alcívar, A., Verdecho, M. J., & Alfaro-Saíz, J. J. (2020). A conceptual framework to manage resilience and increase sustainability in the supply chain. Sustainability, 12(16), 6300.