

Designing sustainable perishable food supply chain under disruption risks: A case study of dairy products

Fatemeh Hosseini¹, Farnaz Barzinpour^{1*}, Milad Askary¹

¹*School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*

Abstract

This study introduces a novel multi-objective mathematical model that optimizes the number of new manufacturers and distribution centers, manages inventory levels at the end of each period, and regulates the flow between different supply chain tiers. The proposed network encompasses various product types, employs multiple transportation modes, and is considered a multi-period time horizon. For this, a new mixed integer programming model under uncertainty is proposed to minimize the supply chain cost, greenhouse gas emissions, and manufacturer water consumption and improve the health and employment index. With these objectives, a sustainable supply chain develops so that the presence of epidemic diseases causes uncertainty in the model. Scenario-based stochastic mixed integer programming includes proposed social, environmental, and economic objective functions. For model performance examination, a real-world case study in the dairy products industry was investigated. The results demonstrate the effectiveness of the proposed model in developing an optimized managerial decision that causes a reduction in costs by as much as 2.6% and greenhouse gas emissions by 5.6%.

Keywords: Sustainable supply chain; Uncertainty; Dairy product; Augmented epsilon constraint; COVID 19.

1. Introduction

The increasing complexity of the factors affecting businesses and the approaching competitive environment has made decision-making challenging for managers. One of the critical factors in the success or failure of a company is the quality of macro-level management decisions. This issue has been studied extensively under various theories in the specific field of facility location science. Farahani and Hekmatfar (2009) defined the location-allocation (LA) problem as locating a set of new facilities so that the transportation cost from facilities to customers is minimized and the optimal number of facilities must be constructed. Mentzer et al. (2001) expressed a supply chain (SC) is a set of firms that pass materials from one place to other places. Typically, several independent firms are involved in

* Corresponding Author

manufacturing a product and placing it in the hands of the end user in a supply chain. All SC members are raw material and component producers, product assemblers, wholesalers, retailers merchants, and transportation companies.

Sustainable development is related to the quality of economic growth, human welfare, and the environment. Therefore, it is considered an environmental, financial, and social issue. Carter and Rogers (2008) expressed that sustainable supply chain management (SCM) means a strategy of integration and simultaneous achievement of social, environmental, and economic objective functions to improve the long-term performance of the SC organizations. Goyal and Giri (2001) expressed that goods can be divided into three main categories: products with an indefinite lifespan, obsolete products, and perishable products. These obsolete products lose value over time due to rapid technological changes and perishable products. According to Tang (2006), supply chain risk (SCR) can be divided into operational and disruption risk. The first results from uncertainty in demand, supply, or cost; the second is caused by natural disasters such as floods and earthquakes or disasters caused by humans such as strikes, quarantines, etc. Mula et al. (2006) classify uncertainty as demand uncertainty, environmental uncertainty, system uncertainty, lead times uncertainty, operation yield uncertainty, and supply lead time uncertainty. Mulvey et al. (1995) presented a scenario-based robust optimization approach for an uncertain environment. This study proposes a mathematical model for designing a sustainable perishable food supply chain network for under distribution. The model aims to optimize the number of new manufacturers and distribution centers, the amount of inventory at the end of each period, and the amount of flow between different levels of the SC while considering three conflicting objective functions, including economic, environmental, and social impacts. The disruption in the proposed model is the prevalence of the pandemic disease COVID-19, which causes uncertainty in the demand parameter. We consider the main contributions of this research as below:

- Considering the disruption caused by epidemic diseases in the design of the food supply chain.
- Investigating the health and safety index of employees during the outbreak of COVID-19 as a social impact.
- Implementing the suggested model with a case study in the dairy industry and comparing its performance.
- Adaptation of disease warning status with possible events as scenarios in the real situation.
- Reducing the costs associated with industrial water consumption by using wastewater treatment.

The remainder of the paper is structured as follows: Section 2 presents the literature review. Section 3 describes the problem and its mathematical formulation. Section 4 presents the real-world case study, computational results, and sensitivity analyses on some crucial parameters, such as the demand forecast accuracy and the cost of setting up new factories. These analyses demonstrate how the model responds to parameter changes and its robustness in different scenarios. Section 5 provides conclusions and suggestions for future research.

2. Literature Review

Mousavi and Bozorgi-Amiri (2017) designed a food supply chain (FSC) as a complex network of inputs and outputs that begins with farm production and all related activities and goes through various stages, such as processing, transportation, and storage until they reach the end of their lives. One of the most critical objective functions of the FSC is to maintain freshness during delivery to the customer. Reducing delivery time or maximizing product quality in this type of SC is crucial for the logistics system. Singh et al. (2020) developed a study that implies that the COVID-19 disease significantly impacts supply chains, especially for human essential goods such as food and medicine, and will face disruption risks. The pandemic has brought to light the vulnerability of supply chains to unexpected disruptions, emphasizing the need for resilience and adaptability in supply chain design. Taking preventive measures such as quarantine laws and other things by the government to control the spread

of the disease has caused the temporary closure of many business units, the loss of job opportunities, the global economy, and a sharp decrease in income. A bi-objective model is proposed by Nasiri et al. (2023) for designing and optimizing a sustainable hierarchical multi-modal hub network. The case of a Turkish network for freight transportation is used to validate the proposed model. The impact of the pandemic on supply chain resilience (SCR) is analyzed by Shen and Sun (2023). They summarized the challenging scenarios that retailing supply chains experienced in China and presented the practical response of JD (<https://www.jd.com>) throughout the pandemic. They explained that the pandemic caused exceptional demand and severe logistical disruptions in China. As a model for calculating safety stocks of perishable products plus showing the effect of perishability on service level, a mathematical model is proposed which shows the effects of long lead times, risk periods, high sales and lead-time variance, and short shelf life adversely affecting perished products. Also, the study investigates and proposes a novel model for calculating total expected waste and costs with a waste quantity constraint (Yigit and Esnaf, 2023; Movahed et al, 2023).

Askary et al. (2024) developed a robust SC model that comprehensively considers uncertain demand and a sustainability approach. In this study, a three-level SC is designed, and then, for optimization, a multi-objective mathematical model is proposed. The sustainability aspect of this model is considered both quantitatively and qualitatively, ensuring a thorough analysis. One of the attractive outlets in this study is product manufacturing line efficiency optimization. Rad and Nahavandi (2018) presented a mathematical model for designing a multi-period, multi-product, multi-level, multi-capacity green closed-loop SC (CLSC) in which suppliers offer small discounts to motivate buyers to purchase more through price reductions. A multi-objective mathematical model for designing a sustainable SCN under conditions of uncertainty is proposed by Tsao et al. (2018). The presented model seeks to choose the technology, the amount of material flow, and the number and optimal location of manufacturers and distribution centers, taking into account the objective functions of reducing the cost and emission of greenhouse gases and increasing the amount of employment. Nurjanni et al. (2017) have developed a new approach to green supply chains, which addresses environmental issues caused by industrialization. The new approach includes a closed-loop network to accommodate the reprocessing pattern of waste products and a multi-objective optimization mathematical model to minimize overall costs and carbon dioxide emissions during SCD. Zhu et al. (2024) studied the impact of COVID-19 as a disruption on life.

Mogale et al. (2019) presented a new mathematical model that studies the reduction of costs and greenhouse gas emissions from establishing facilities, transportation, and inventory maintenance. The model provides practical decisions such as the location of warehouses, the flow between facilities, stock levels at the end of each period, and the number of vehicles. Due to the NP-hard nature of the model, the multi-objective particle swarm optimization algorithm (MOPSO) and NSGA-II have been used. Rahimi et al. (2019) presented a sustainable multi-objective mathematical model considering the conditions of risk aversion and the value criterion against conditional risk for designing and planning the SCN under uncertainty in transportation cost, demand, and rate of demand growth. This research presents a mixed integer nonlinear mathematical model (MINLP). Govindan et al. (2019) presented a mathematical model for distribution network design that integrated a multi-depot vehicle routing problem considering multiple products and time windows with strategic network design decisions. The model has two goals: economic, environmental, and social. Alkaabneh et al. (2020) presented an inventory-routing model for perishable products, which is the optimal solution for scheduling and routing vehicles with the goals of increasing supplier profits and reducing costs caused by transportation, inventory maintenance, and greenhouse gas emissions based on vehicle loads are obtained. Sazvar et al. (2018) developed a multi-objective linear model for a sustainable supply chain of perishable agricultural products. These products are produced in two ways, organic and conventional, and this research aims to balance the production and consumption of these two methods, taking into account the reduction of costs and environmental effects and increasing the health of society.

Yakavenka et al. (2019) presented a mixed integer linear programming model for the perishable FSC about the three dimensions of sustainability. The performance of the model is in the form of a case study in the fruit industry that is from Southeast Europe to be exported to the northeastern region of Europe; it is examined. Mohammed and Wang (2017) proposed a three-level meat SC consisting of farms,

slaughterhouses, and customers is considered, which seeks the optimal number and location of farms and slaughterhouses and the number of workers, as well as the amount of flow between different levels of the supply chain. Abbasi et al. (2021) designed a nonlinear mathematical model to create a third-party logistics (3PL) network to consider product perishability and possible disruption in hubs and distribution centers. Also, three approaches: retrofitting facilities, backup facilities, and multiple resources, are included as resilience strategies. The possibility of disruption in the facility is considered uncertain, and fuzzy programming was used to deal with the existing uncertainty. Mohammadi et al. (2023) developed a multi-objective mixed-integer nonlinear programming model for a four-level sustainable supply chain of a perishable product with price-dependent demand and deterioration rates. They aim to ascertain the optimal pricing policy and cycle length to maximize profit, achieve specific social objectives, and minimize the total cost and adverse environmental impacts. The proposed model determines the deterioration rate of each product according to its expiration date, the optimal location of supply-side facilities, and the flow rate between the facilities based on the selected mode of delivery. The products are delivered to the retailers by a mechanized transportation system directly from the PC or indirectly through the DCs. In Table 1, previous studies are compared together, as well as our research. Some of the most importance of gap research can be expressed as: insufficient attention to consider the social aspect of sustainability in food industry supply chains, insufficient attention to environmental issues such as noise pollution, sewage treatment, etc., insufficient attention to studies in the field of disorders caused by the outbreak of epidemic diseases, insufficient attention to studies in the field of multi-channel distribution system, and insufficient attention to the use of wastewater treatment.

Table.1. Comparison of literature and this work

Article	Type of decision				Number of function		Type of function			Uncertainty	Multi Product	Case study
	scheduling	Location	Allocation	Inventory	Single objective	Multi objective	Economic	Social	Environmental			
Mousavi and Bozorgi (2017)	*	*	*			*	*	*	*			
Mohammed and Wang (2017)		*	*			*	*	*	*	*		*
Sazvar et al. (2018)				*		*	*	*	*		*	
Rad and Nahavandi (2018)		*	*	*		*	*	*	*	*	*	*
Tsao et al. (2018)		*	*	*		*	*	*	*	*		
Mogale et al. (2019)		*	*			*	*					
Rahimi et al. (2019)		*	*			*	*	*	*	*	*	
Govindan et al. (2019)	*	*	*			*	*	*	*		*	
Yakavenka et al. (2019)			*			*	*	*	*			*
Alkaabneh et al. (2020)	*			*		*	*		*		*	
Abbasi et al. (2021)		*	*	*		*				*	*	*
Shen and Sun. (2023)								*				*
Yigit and Esnaf (2023)				*	*		*	*	*	*	*	*
Nasiri et al. (2023)	*	*	*			*	*	*	*			
Mohammadi et al. (2023)		*	*	*		*	*	*	*			*
Milad Askary et al. (2024)		*	*	*		*	*	*	*	*	*	*
This research	*	*	*	*		*	*	*	*	*	*	*

3. Problem statement

The food industry plays a crucial role as an intermediary loop between the agricultural and livestock industries. Given the direct relationship between the food chain and human health, the FSC is very complex, mainly due to the perishability of food products in time windows. In recent years, sustainability has become an essential consideration in the food industry, with environmental and social dimensions added to the traditional cost criteria. However, sustainability should only be considered in the SC design. In that case, managers may set aside the sustainability objective function in the event of a disruption to the chain and prioritize returning to the original state as quickly as possible. Therefore, it is crucial to consider the possibility of disruption from the outset, integrating the sustainability objective function into the FSC design to ensure the chain can continue to operate in situations involving disruption and damage, whether natural or human-made.

This study considers the prevalence of epidemic diseases as a source of disorder, leading to uncertainty in demand, and emphasizes the health and safety index of employees during the outbreak of COVID-19. The SC under study is an integrated supply chain, as shown in Fig. 1. Raw materials are initially supplied from different suppliers, transported to production centers to manufacture the final products, and then delivered to customers. The SC is designed for perishable foods with a specific shelf life, and raw materials and products are transported using heterogeneous refrigerated vehicles between different chain levels. The locations of suppliers and customers are fixed. The model aims to determine the optimal location of manufacturers and distribution centers among the proposed locations, the flow of materials between different levels of the SC, and the amount of inventory in distribution centers at the end of each period. Noteworthy, the meaning of raw milk is one that gets from milking the cow before any pasteurized and sterilized milk process in manufactories.

The model minimizes chain costs, reduces environmental impact, and increases social responsiveness. It has three objectives:

- Minimizing SC costs, including facility construction costs, raw material purchase costs, production costs, transportation costs, inventory maintenance costs, human resources costs, and wastewater treatment costs.
- Minimizing CO₂ emissions, which include carbon dioxide emissions from new facilities, inventory maintenance, and transportation between different levels of the SC, to reduce environmental impact.
- Maximizing the social accountability of the SC, including job creation and employee health and safety during the outbreak of COVID-19 disease. The proposed model integrates these three objectives to achieve a sustainable and responsive food supply chain.

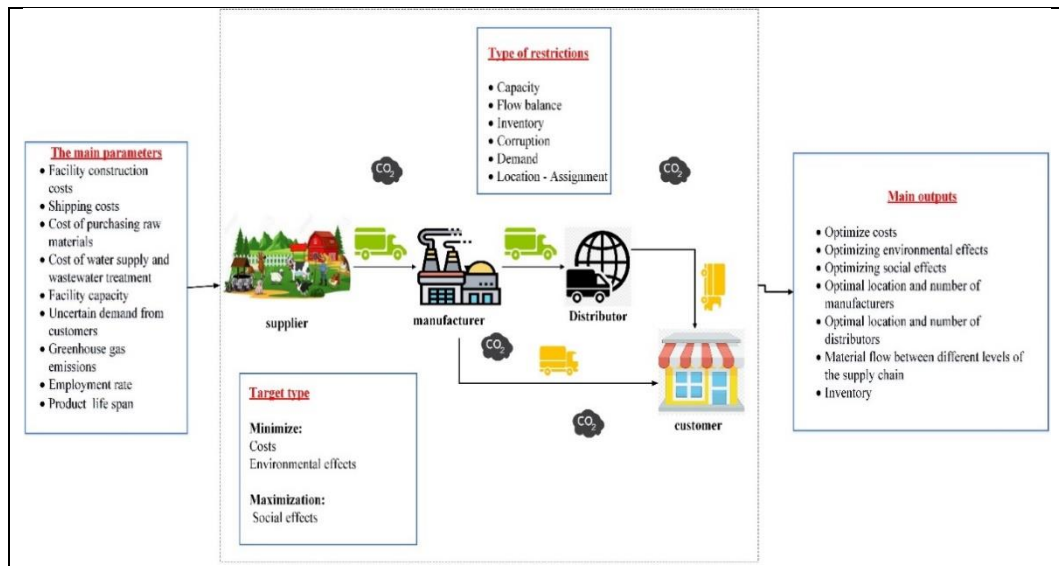


Fig.1. Conceptual model

4. Mathematical model

This section discusses mathematical modeling of the problem of perishable FSC design with a sustainability and disruption risk approach. After defining the indicators, parameters, and decision variables, the objective functions of the two-stage planning model are developed, and the model constraints are described.

Assumption:

- The average salary is the same and fixed by manufacturers (personnel cost).
- The average salary is the same and fixed by distribution centers (personnel cost).
- The model is multi-period and multi-product.
- The products are perishable and have a specific shelf life. Also, the expiration period of each of them is an integer multiple of the length of the periods.
- Products are sent to customers either directly from the production centers or indirectly by distribution centers.
- Customer demand is considered uncertain due to fluctuations during the coronavirus outbreak.
- Suppliers, manufacturers, and distribution centers have a specific and fixed capacity.
- Only one type of raw material is considered for the production of products, and the percentage of its use in each product is an input parameter.
- Heterogeneous network vehicles are considered.
- It is possible to store products in distribution centers and the product warehouse management system is First-Expired-First-Out (FEFO) due to the importance of expiration dates in products with high perishability rates.
- The goods reach the customer at the time of their consumption and there is no possibility of product spoilage in the warehouse.

Mathematical model signs

- **Indices, parameters and decision variables of the problem model are:**

s Supplier Index

$s = 1, \dots, S$

p	Index related to manufacturer	$p = 1, \dots, P$
w	Index related to distribution centers	$w = 1, \dots, W$
c	Index related to customers	$c = 1, \dots, C$
m	Index related to the transportation vehicle	$m = 1, \dots, M$
q	Index related to the type of products	$q = 1, \dots, Q$
t	Index for the period	$t = 1, \dots, T$
ω	Index related to scenarios	$\omega = 1, \dots, \omega$
f_p	Fixed cost of constructing a manufacturer center p (Rial)	
$f_w CT_{sp}^m$	Fixed cost of constructing a distribution center w (Rial)	
CT_{sp}^m	Cost of transporting each unit of raw milk from supplier s to manufacturer p by transport vehicle m (Rial/ Kilometer)	
CT_{pw}^m	Cost of transporting each unit of raw milk from manufacturer p to distributor w by transport vehicle m (Rial/ Kilometer)	
CT_{wc}^m	Shipping cost of each product unit from distributor w to customer c with transport vehicle m (Rial per Kilometer)	
CT_{pc}^m	Shipping cost of each product unit from manufacturer p to customer c with transport vehicle m (Rial per Kilometer)	
C_s	Cost of purchasing each kilogram of raw milk from the supplier s (Rial per ton)	
HC_{wq}	Cost of maintaining product inventory q in the distribution center w (Rial per ton)	
$Pr c_{pq}$	The production cost of product q in the manufacturer center p (Rial per ton)	
$empp$	The average cost of manpower in manufacturer centers (Rial per worker)	
$empw$	The average cost of manpower in distribution centers (Rial per worker)	
CW_p	Cost of treatment of each effluent unit in the manufacturer center p (Rial per m^3)	
CF_p	Cost of refining each unit of fresh water in the manufacturer center p (Rial per m^3)	
δ_p	Cost of fines for each unit of untreated wastewater in the manufacturer center p (Rial per m^3)	
PC_{pq}	Manufacturer capacity p of product q (ton)	
sc_s	Supplier capacity for supply Raw milk s (ton)	
IC_{wq}	Product storage capacity q in the distribution center w (ton)	
WC_p	Maximum effluent treatment capacity in the manufacturer center p (m^3)	
$d_{cqt\omega}$	Customer demand c for product q in period t under scenario ω (ton)	
$Enve_p$	The amount of greenhouse gas emitted in terms of grams due to the construction of the manufacturer p	

Env_{ew}	The amount of greenhouse gas emitted in terms of grams due to the construction of the distribution center w
$Env_{h_{wq}}$	The amount of greenhouse gas emitted in terms of grams due to the storage of product stock q in the distribution center w
Env_{sp}^m	The amount of greenhouse gas emitted in grams due to the transport of each unit of raw milk from supplier s to manufacturer p with transport vehicle m
Env_{pw}^m	The amount of greenhouse gas emitted in terms of grams due to the transport of each unit of product from manufacturer p to distribution center w with transport vehicle m
Env_{wc}^m	The amount of greenhouse gas emitted in grams to transport each unit of product from the distribution center w to the customer c with a transport vehicle m
Env_{pc}^m	The amount of greenhouse gas emitted in grams to transport each unit of product from manufacturer p to customer c with transport vehicle m
ld	Average number of lost working days due to Covid-19 disease
jcp_p	Number of job opportunities created in case of manufacturer construction p
jcw_w	Number of job opportunities created in case of construction of distribution center w
up_p	Unemployment rate at the proposed site for manufacturer p
uw_w	Unemployment rate at the proposed location for the distribution center w
si_{max}^{hs}	The greatest possible social impact on the health and safety of employees
si_{min}^{hs}	The least possible social impact on the health and safety of employees
si_{max}^{jc}	Maximum possible social effects related to worker employment
si_{min}^{jc}	The least possible amount of social effects related to worker employment
φ_{hs}	Coefficient of the importance of employees' health and safety index
φ_{jc}	Significance Coefficient of worker employment index
τ_q	Product shelf life q (days)
r_q	Percentage of raw material used in product production q
γ	The maximum acceptable level for the release of untreated effluent
ρ_p	Effluent treatment rate in the production center p
$water_p$	The amount of water required to prepare each unit of raw material in the manufacturer center p (m ³ per ton)
pr_ω	Probability of occurrence of scenario ω
G	big number

- **Decision variable**

$x_{spt\omega}^m$	Raw milk flow from supplier s to manufacturer p with transport vehicle m in period t under scenario ω
$x_{pwt\omega}^{mq}$	Product flow q from manufacturer p to distributor w with transport vehicle m in time period t under scenario ω
$x_{wct\omega}^{mq}$	Product flow q from distributor w to customer c with transport vehicle m in period t under scenario ω
$x_{pct\omega}^{mq}$	Product flow q from manufacturer p to customer c with transport vehicle m in time period t under scenario ω
$int_{wqt\omega}$	Product inventory q at the distribution center w at the end of period t under scenario ω
op_p	Binary variable; Its value is one if manufacturer p is constructed, otherwise zero.
ow_w	Binary variable; its value is one if the distribution center w is constructed, otherwise zero.

Pishvaei et al. (2012) surveyed the health and safety of employees. The index "Number of working days lost due to coronary heart disease" can be used according to Table 2.

Table.2. Social Impacts and Measures (Pishvaei et al. 2012)

Quantifying	Social index	beneficiary
Number of potentially dangerous products (product risk)	Consumption safety	Customers
Number of working days lost due to job problems	Safety	Staff
Number of job opportunities	Justice in working conditions	
Number of job opportunities	General development	Public
The amount of waste generated	Environmental Quality	

To normalize the measured social effects, the human development index according to relations (1) and (2) has been used, which si_{min}^* , si_{max}^* , si^* and si_{nor}^* indicates the minimum possible, the maximum possible, the actual value and the normalized value of the corresponding index. It should be noted that Equations (1) and (2) are used when minimizing and maximizing the indicators are desirable, respectively, and finally, according to the importance of the indicators, a weight is assigned to them.

$$si_{nor}^* = \frac{si_{max}^* - si^*}{si_{max}^* - si_{min}^*} \quad (1)$$

$$si_{nor}^* = \frac{si^* - si_{min}^*}{si_{max}^* - si_{min}^*} \quad (2)$$

As a result, according to the contents, the function of the third function is as follows:

$$\text{social effect} = \varphi_{jc} si_{nor}^{jc} - \varphi_{hs} si_{nor}^{hs} \quad (3)$$

$$\begin{aligned} \text{social effect} = & \varphi_{jc} \left(\frac{(\sum_p jcp_p up_p op_p + \sum_w jcw_w uw_w ow_w) - si_{min}^{jc}}{si_{max}^{jc} - si_{min}^{jc}} \right) \\ & + \varphi_{hs} \left(\frac{si_{max}^{hs} - (\sum_p ldop_p + \sum_w ldow_w)}{si_{max}^{hs} - si_{min}^{hs}} \right) \end{aligned} \quad (4)$$

Using the signs and objective functions introduced in the previous section, the proposed mathematical model of the problem includes:

$$\begin{aligned} \min z_1 = & \left(\sum_p f_p op_p + \sum_w f_w ow_w \right) + \left(\left(\sum_{\omega} pr_{\omega} \left(\sum_t \sum_m \sum_q \sum_p \sum_w x_{pwt\omega}^{mq} \right. \right. \right. \\ & + \left. \left. \sum_t \sum_m \sum_q \sum_p \sum_c x_{pct\omega}^{mq} \right) \right) PrC_{pq} \right) \\ & + \left(\sum_{\omega} pr_{\omega} \left(\sum_t \sum_m \sum_s \sum_p CT_{sp}^m x_{spt\omega}^m + \sum_t \sum_m \sum_q \sum_p \sum_w CT_{pw}^m x_{pwt\omega}^{mq} \right. \right. \\ & + \left. \left. \sum_t \sum_m \sum_q \sum_w \sum_c CT_{wc}^m x_{wct\omega}^{mq} + \sum_t \sum_m \sum_q \sum_p \sum_c CT_{pc}^m x_{pct\omega}^{mq} \right) \right) \\ & + \left(\sum_{\omega} \sum_t \sum_q \sum_w pr_{\omega} HC_{wq} int_{wqt\omega} \right) + \left(\sum_{\omega} \sum_t \sum_m \sum_s \sum_p pr_{\omega} C_s x_{spt\omega}^m \right) \\ & + \left(\sum_p jcp_p empp op_p + \sum_w jcw_w empw ow_w \right) \\ & + \left(\left(\sum_{\omega} pr_{\omega} \left(\sum_t \sum_m \sum_s \sum_p \rho_p water_p CW_p \right. \right. \right. \\ & + \left. \left. \sum_t \sum_m \sum_s \sum_p (1 - \rho_p) water_p \delta_p \right. \right. \\ & + \left. \left. \sum_t \sum_m \sum_s \sum_p (1 - \rho_p) water_p CF_p \right) x_{spt\omega}^m \right) \end{aligned} \quad (5)$$

$$\begin{aligned}
\min z_2 = & \left(\sum_p Enve_p op_p + \sum_w Enve_w ow_w \right) + \left(\sum_\omega pr_\omega \left(\sum_t \sum_m \sum_s \sum_p Envt_{sp}^m x_{spt\omega}^m \right. \right. \\
& + \sum_t \sum_m \sum_q \sum_p \sum_w Envt_{pw}^m x_{pwt\omega}^{mq} + \sum_t \sum_m \sum_q \sum_w \sum_c Envt_{wc}^m x_{wct\omega}^{mq} \\
& + \left. \left. \sum_t \sum_m \sum_q \sum_p \sum_c Envt_{pc}^m x_{pct\omega}^{mq} \right) \right) \\
& + \left(\sum_\omega \sum_t \sum_q \sum_w pr_\omega Envh_{wp} int_{wqt\omega} \right)
\end{aligned} \tag{6}$$

$$\begin{aligned}
\max z_3 = & \varphi_{jc} \left(\frac{(\sum_p jcp_p up_p op_p + \sum_w jcw_w uw_w ow_w) - si_{min}^{jc}}{si_{max}^{jc} - si_{min}^{jc}} \right) \\
& - \varphi_{hs} \left(\frac{si_{max}^{hs} - (\sum_p ldop_p + \sum_w ldow_w)}{si_{max}^{hs} - si_{min}^{hs}} \right)
\end{aligned} \tag{7}$$

s.t:

$$\sum_m \sum_t \sum_q \sum_w x_{pwt\omega}^{mq} + \sum_m \sum_t \sum_q \sum_c x_{pct\omega}^{mq} \leq Gop_p \quad \forall p, \omega \tag{8}$$

$$\sum_m \sum_t \sum_q \sum_c x_{wct\omega}^{mq} \leq Gow_w \quad \forall w, \omega \tag{9}$$

$$\sum_m \sum_t \sum_s x_{spt\omega}^m \leq Gop_p \quad \forall p, \omega \tag{10}$$

$$\sum_p \sum_m x_{spt\omega}^m \leq sc_s \quad \forall s, t, \omega \tag{11}$$

$$\sum_m \sum_w x_{pwt\omega}^{mq} + \sum_m \sum_c x_{pct\omega}^{mq} \leq PC_{pq} op_p \quad \forall p, q, t, \omega \tag{12}$$

$$int_{wqt\omega} \leq IC_{wq} ow_w \quad \forall w, q, t, \omega \tag{13}$$

$$\sum_s \sum_m x_{spt\omega}^m \geq r_q \left(\sum_m \sum_w x_{pwt\omega}^{mq} + \sum_m \sum_c x_{pct\omega}^{mq} \right) \quad \forall p, q, t, \omega \tag{14}$$

$$\sum_m \sum_p x_{pwt\omega}^{mq} + int_{wqt-1\omega} \geq \sum_m \sum_c x_{wct\omega}^{mq} \quad \forall w, q, t, \omega \quad (15)$$

$$int_{wqt\omega} = int_{wqt-1\omega} + \sum_m \sum_p x_{pwt\omega}^{mq} - \sum_m \sum_c x_{wct\omega}^{mq} \quad \forall w, q, t, \omega \quad (16)$$

$$\sum_m \sum_w x_{wct\omega}^{mq} + \sum_m \sum_p x_{pct\omega}^{mq} = d_{cqt\omega} \quad \forall c, q, t, \omega \quad (17)$$

$$int_{wqt\omega} \leq \sum_m \sum_{t'=t}^{t+\tau_q-1} \sum_c x_{wct'\omega}^{mq} \quad \forall w, q, t, \omega \quad (18)$$

$$\sum_m \sum_t \sum_s (1 - \rho_p) water_p x_{spt\omega}^m \leq \gamma \quad \forall p, \omega \quad (19)$$

$$\sum_m \sum_t \sum_s \rho_p water_p x_{spt\omega}^m \leq WC_p op_p \quad \forall p, \omega \quad (20)$$

$$x_{spt\omega}^m, x_{pwt\omega}^{mq}, x_{wct\omega}^{mq}, x_{pct\omega}^{mq}, int_{wqt\omega} \geq 0 \quad \forall s, p, w, c, t, m, q, \omega \quad (21)$$

$$op_p, ow_w \in \{0,1\} \quad \forall p, w \quad (22)$$

Equation (5) relates to the economic objective function of the problem, which minimizes the cost of the entire supply chain. Minimization of the environmental effects of carbon dioxide emissions is also shown in Equation (6). Equation (7) relates to maximizing the supply chain's social impact, including job creation and employee health and safety during the COVID-19 outbreak. Constraints (8), (9), and (10) are related to the amount of material flow between different levels of the supply chain, provided that production centers and distribution centers are established. Constraints (11), (12), and (13) indicate the capacity of suppliers, manufacturers, and distribution centers, respectively. Constraints (14) and (15) are related to network flow balance. Constraint (16) indicates the amount of inventory in the distribution center in each period. Satisfying customer demand through direct and indirect shipping is also stated in Constraint (17). Constraint (18) shows the maximum inventory of each product in each period in the warehouse of each distribution center according to the issue of product corruption. Product corruption is impossible because the warehouse management system is considered the first expired first out (FEFO). Constraints (19) and (20) are related to the environmental dimension of effluent treatment. Constraint (19) indicates the maximum acceptable level for releasing untreated effluent into the environment, and Constraint (20) is related to the refinery capacity of production centers. Constraints (21) and (22) introduce the problem of decision variables.

5. Case study

This research focuses on the proposed model for one of the "dairy manufacturers" in Tehran, Iran. The company began its activities in 1338. The manufacturing area is approximately 83333 m². Currently, the sub-commercial units of this dairy manufacturer include Shahrekord, Sanandaj, and Sari, responsible for distributing goods to neighboring provinces. The company's workforce consists of 1460

employees. This manufacturer's vision is to expand its market share among its competitors. The company's products are divided into dairy and ice cream. Dairy products include pasteurized and sterilized milk, cream, butter, yogurt, cheese, buttermilk, and desserts. The raw milk, one of the primary raw materials of dairy products, is purchased daily from various suppliers and transported to the central manufacturer in Tehran. The products are then sent directly to customers in nearby provinces such as Tehran, Karaj, Qazvin, and Qom in refrigerated trucks with a capacity of 10 tons. Some products are sent to distribution centers in other provinces, such as Sari, Sanandaj, and Shahrekord, by refrigerated trailers with a capacity of 22 tons and then reach the customers of that province. Due to toxic substances, specific rules and regulations are defined by the Environmental Protection Agency for all manufacturers to establish a treatment plant unit to purify spoiled products, remove harmful substances, and bring them to the COD index approved by the Ministry of Health. COD indicates the amount of oxygen required for oxidation, which the Environmental Protection Agency agreed to release waste products into municipal wastewater.

5.1. Candidate locations

The dairy manufacturer intends to build at least one manufacturer and one distribution center in other parts of Iran to gain more market share, considering the issue of competitors. Interviews with industry experts determined these candidate locations. According to the experts of dairy manufacturers, there is a need for the dairy manufacturer to be close to the provinces that allocate the most milk production, as well as the issue of competitors and efforts to gain more market share. Table 3, related to the latest available statistics, is about milk production in the country's provinces. Potential locations for constructing the Karaj, Mashhad, and Isfahan manufacturers are suggested. Also, because a capillary sales policy is considered in the dairy manufacturer, experts believe in building distribution centers in densely populated cities of Iran. Therefore, according to Fig.2, which is related to the latest census statistics for 2015, Fars, Khuzestan, East Azerbaijan, and Kerman are proposed as candidate locations for the construction of distribution centers due to the existence of competitors.

Table 3. Distribution of milk production (first 6 months of year)

Row	Province	Amount(x* 100 tons)	Row	Province	Amount(x* 100 tons)
1	Esfahan	4981	16	Ardebil	353
2	Tehran	5717	17	Mazandaran	340
3	Qazvin	2368	18	Zanjan	272
4	Fars	2146	19	Golestan	247
5	Razavi khorasan	2009	20	South khorasan	241
6	Alborz	1353	21	Khuzestan	184
7	Yazd	754	22	Lorestan	144
8	East Azerbaijan	724	23	West Azerbaijan	114
9	Markazi	661	24	Kurdistan	103
10	Semnan	572	25	North khorasan	96
11	Hamedan	514	26	Kohgiluyeh	90
12	Qom	512	27	Ilam	24
13	Kermanshah	426	28	Sistan and baluchestan	22
14	Kerman	378	29	Gilan	18
15	Chaharmahal and bakhtiari	369	30	Bushehr	16

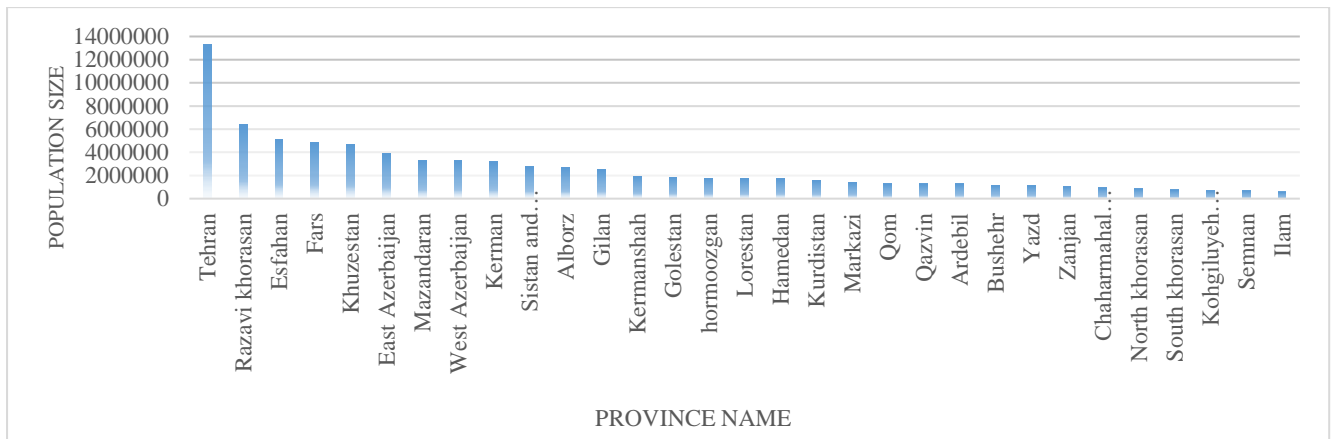


Fig.2. Population by the province in 2015

Based on this information, in Fig.3, the current logistics network of the case study can be seen along with the proposed locations for the construction of new facilities.

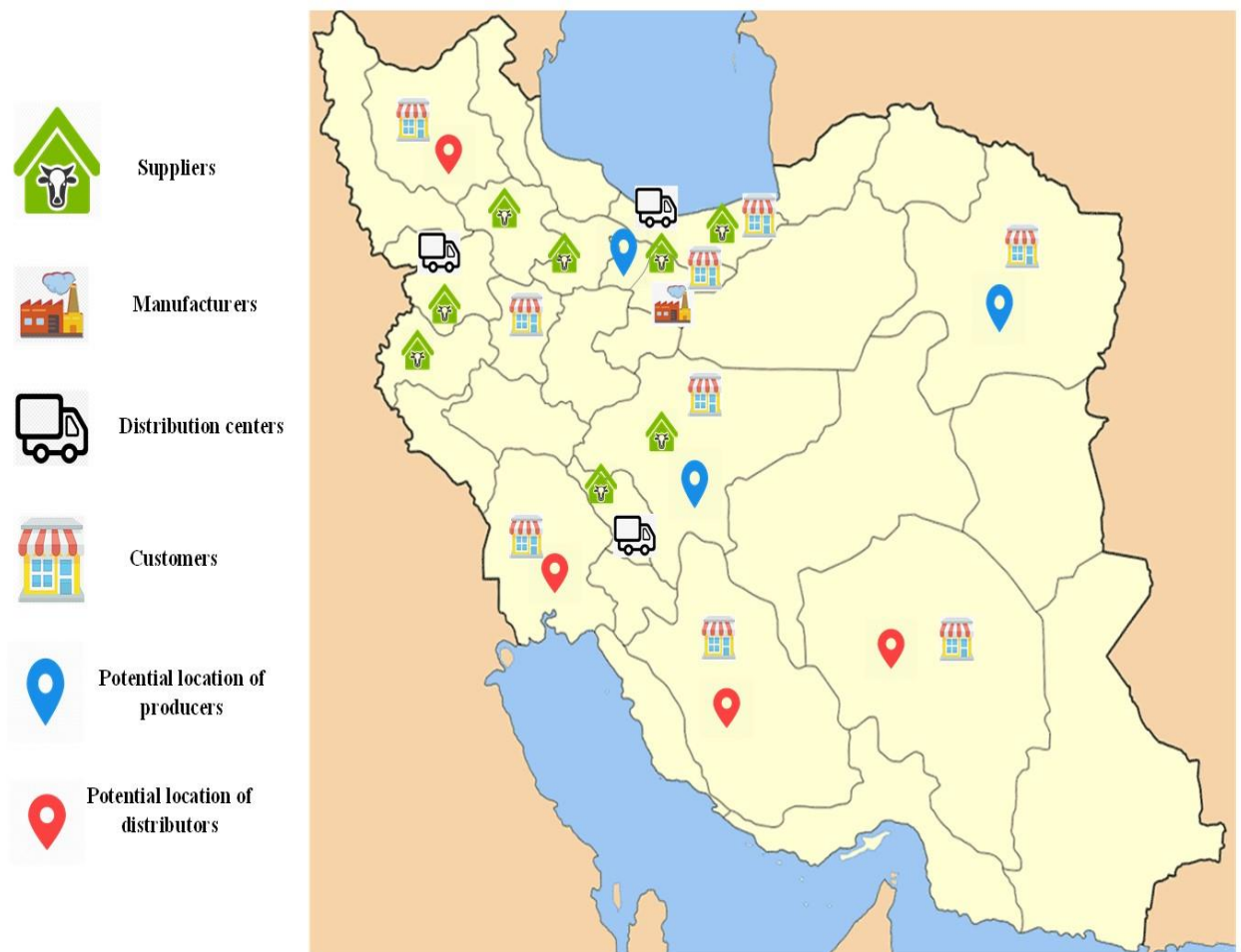


Fig.3. Diagram of the current logistics network of the case study

5.2. Data collection

The country of Iran consists of 31 provinces, and in this case study, nine demand points are considered according to the opinion of experts, that each demand point covers its neighboring provinces; these demand points and the provinces covered by them can be seen in which Table 4.

Table 4. Demand points

Points Demand	Covered Areas	Points Demand	Covered Areas
Tehran	Tehran-Karaj-Qom -Qazvin	Kerman	Kerman-Yazd-Birjand-Zahedan
Mashhad	Mashhad-Bojnoord	Tabriz	Tabriz-Urmia-Ardabil
Esfahan	Isfahan-Arak-Semnan	Sari	Sari-Gorgan-Rasht
Shiraz	Shiraz-Bushehr-Bandar Abbas-Yasouj	Hamedan	Hamedan-Kermanshah-Zanjan-Sanandaj
Ahvaz	Ahvaz-Ilam-Shahrekord-Khorramabad		






5.3. Uncertainty in the problem

The first, dimension of problem depicts on the Table 5.a. The next, to determine the scenarios of the stochastic programming problem, the index refers to the Ministry of Health, Treatment, and Medical Education statistics. During the outbreak of the COVID-19 disease, the cities of the country were classified into four colors based on the number of daily hospitalizations: blue, yellow, orange, and red (see Table 5.b.). In yellow cities, there are four hospitalizations per 100,000 people per day; in orange cities, there are six hospitalizations per 100,000 people per day; and in red cities, there are ten hospitalizations per 100,000 people per day. The number of daily hospitalizations in blue cities is less than that in yellow cities. For the proposed model, five scenarios with probabilities determined by experts have been considered. This thorough statistical analysis, along with interviews with the dairy manufacturer experts, has led to the consideration of a 0%, 5%, 10%, 15%, and 20% decrease in demand for scenarios one to five, respectively.

Table.5. a. Sets dimensions

Row	Sets	Set identification
1	s=8	Qazvin-Tehran-Zanjan-Chaar mahal Bakhtiari- Isfahan-Kurdistan-Kermanshah
2	p=3	Karaj-Mashhad-Isfahan
3	w=4	Shiraz-Ahwaz-Kerman-Tabriz
4	c=9	Tehran-Mashhad-Isfahan-Shiraz-Ahwaz-Kerman-Tabriz-Sari-Hamadan
5	m=2	10 tons capacity-22 tons capacity
6	q=2	Milk - cream
7	t=7	Period
8	w=5	Scenarios

Table 5.b. Detail of scenarios

Scenario	Interpretation	Probability of the scenario
 Green	Before COVID-19 disease (basic)	0.25
 Blue	Low risk	0.18
 Yellow	Moderate risk	0.22
 Orange	Dangerous	0.20
 Red	Very dangerous	0.15

5.4. Computational results

According to Table 4, Table 5.a, and Table 5.b and so by adding case study data, the proposed mathematical model is solved using GAMS 25.1 software with Cplex Solver on a personal computer with Intel Core i5 and 4GB RAM specifications. Also, the epsilon constraint method is used to solve multi-objective model. According to the experts, the cost objective function is considered the primary objective function, and the environmental and social objective functions are considered constraints in the evolved constraint epsilon method. The calculation results of the last optimal Pareto solution resulting from the solution of the model in deterministic states for the five existing scenarios and the random model in ten consecutive iterations can be seen in Table 6.a. Additionally, the optimal solution of location variables and flow variables present on the Table 6.b and Table 6.c. The places selected for the construction of facilities are shown in Fig. 4.

Table .6.A. The results of solving the proposed problem in deterministic and random mode

Social effects	Environmental effects	Total cost	Model	Solve time (second)
894.8	4.63E+07	8.32E+10	model under scenario 1	2341
537.7	4.15E+07	8.00E+10	model under scenario 2	2468
304.7	3.90E+07	7.68E+10	model under scenario 3	2289
304.7	3.36E+07	7.10E+10	model under scenario 4	2465
304.7	2.38E+07	7.04E+10	model under scenario 5	2403
225.6	4.71E+07	7.73E+10	A stochastic model	3571

Table.6.b. The manufacturer and distribution decision variables under scenarios

OPP	OWw	Demand	Model
Karaj	Tabriz-Ahwaz	0% Decrease	Model under scenario 1
Karaj	Tabriz-Ahwaz	5% Decrease	Model under scenario 2
Karaj	Ahwaz	10% Decrease	Model under scenario 3
Karaj	Ahwaz	15% Decrease	Model under scenario 4
Karaj	Ahwaz	20% Decrease	Model under scenario 5
Isfahan	Ahwaz	Average-Decrease	A stochastic model

Table.6.c. The results of solving the proposed problem in deterministic and random mode

X variables (Flows)	Supplier	Manufacturer	Distribution center	Costumer
Supplier	-	Isfahan	-	-
Manufacturer	-	-	Ahwaz	Tehran-Mashhad-Isfahan
Distribution center	-	-	-	Shiraz-Ahwaz Kerman-Tabriz Sari-Hamadan
Costumer	-	-	-	-

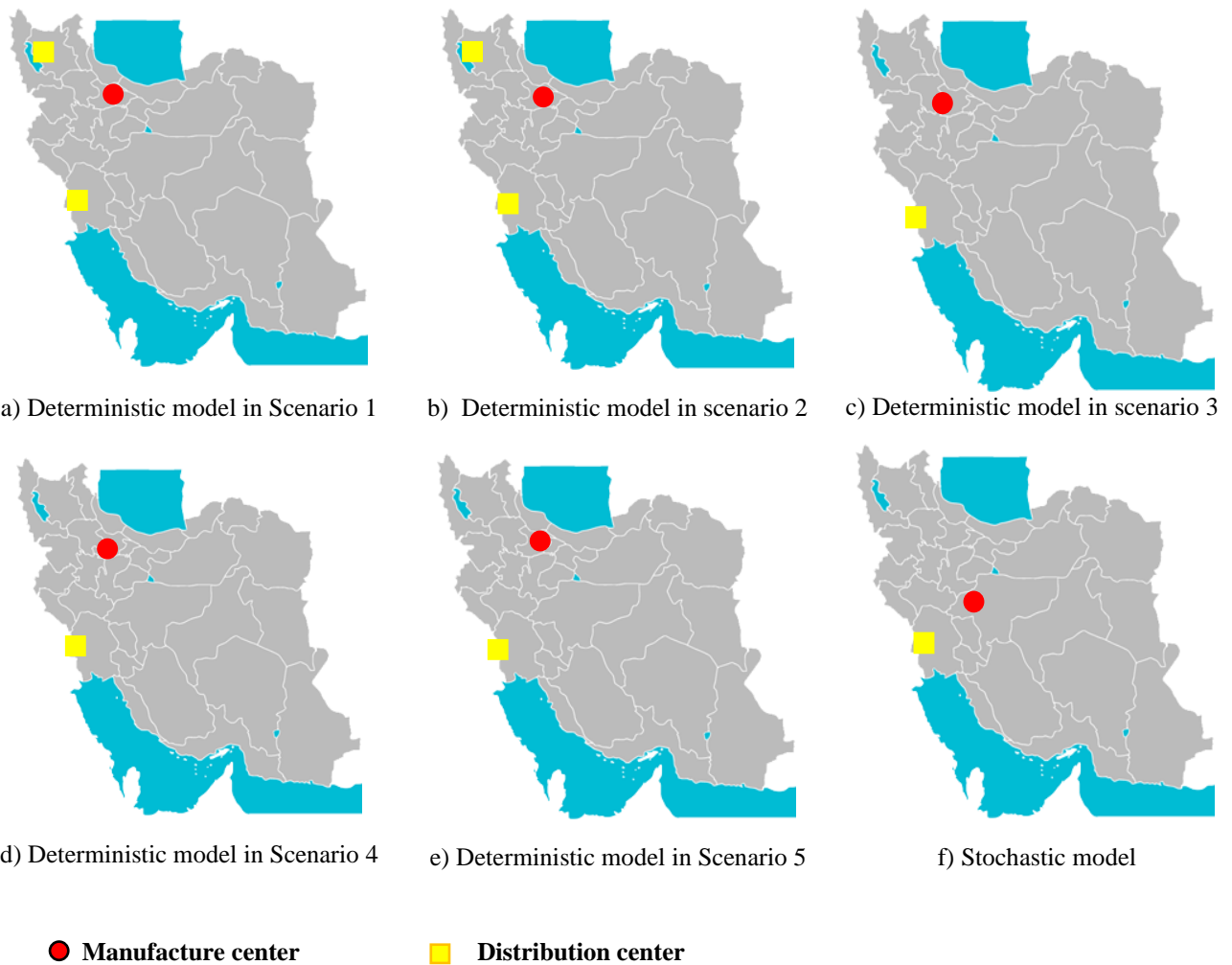


Fig.4. Comparisons between the deterministic model with different scenarios and the stochastic model

6. Verification and Validation for model

6.1. Sensitivity analysis under scenarios

In this section, the sensitivity of the model to the demand parameter is investigated. Five scenarios with 0%, 5%, 10%, 15%, and 20% reduction in demand have been considered, and the results are shown. With the decrease in demand, the value of the first objective function is expected to decrease because the amount of raw material purchased and the amount of movement between different levels of the SC will decrease. Consequently, the cost of the network will decrease, and the environmental impact will be reduced due to the reduced transportation.

Also, Fig.5 to Fig.7 shows the amount of changes in economic, environmental, and social objective functions relative to demand changes in different scenarios, respectively. The results are consistent with the expected logic and indicate the correct behavior of the proposed model.

6.2. Conflict of objective functions

In the proposed model, three objective functions were introduced. The first objective function minimizes network costs, the second objective function minimizes environmental effects, leading to the

reduction of greenhouse gas emissions, and the third objective function maximizes the social aspect of the network, leading to an increase in employment and employee health and safety. Due to the conflict between these objectives, only one optimal solution optimizes all objectives simultaneously. Typically, when the value of one objective improves, the other objective functions worsen. This property is known as non-dominated solutions. Pareto diagrams of two objective functions are presented to investigate this conflict without considering the other objective function. Fig. 8 shows the conflict diagrams of the proposed problem, the objective function of minimizing network costs and maximizing social effects conflict with each other. The cost objective function tends to reduce the construction of production and distribution centers, which causes a decrease in the social objective function, because the social objective function aims to maximize employment and employee health and safety. Fig. 9 displays the relationship between these two objective functions well. Comparing the system's costs objective function with the network's environmental objective function is important because the model tends to transport over long distances to reduce system costs due to lower transportation costs compared to the construction of facilities, which increases gas emissions. Most companies tend to travel with cheaper modes of transportation, which increases the adverse environmental effects. Fig. 10 shows that with the reduction of system costs, the amount of greenhouse gas emissions increases. The environmental objective function tends not to build production and distribution centers that minimize the amount of greenhouse gas emissions, leading to the reduction of social effects. As a result, the environmental objective function conflicts with the social aspect of the network.

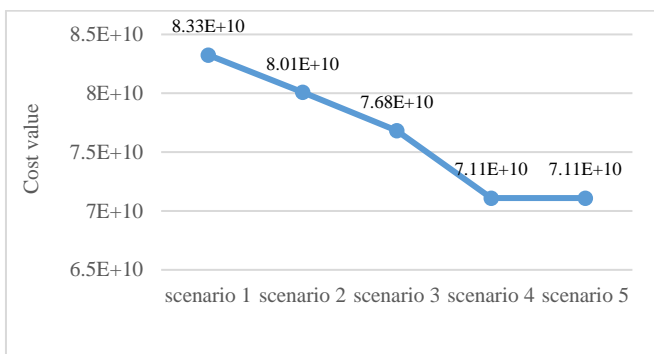


Fig.5. The demand change effect on the cost value

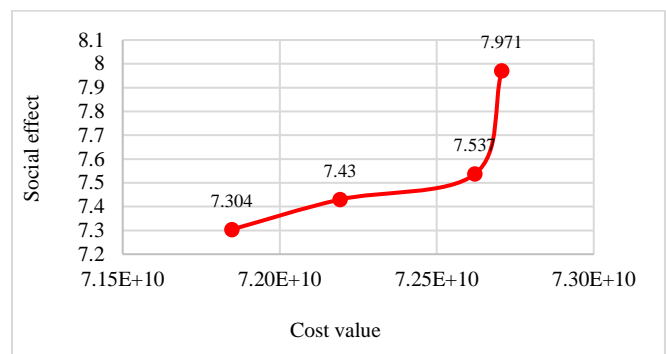


Fig.8. Conflict between social and cost value

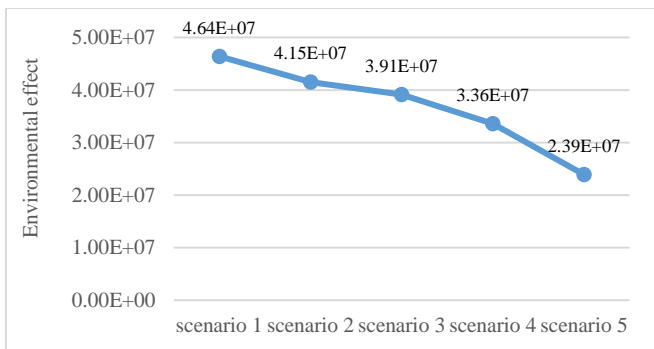


Fig.6. The demand change effect on the environment effect

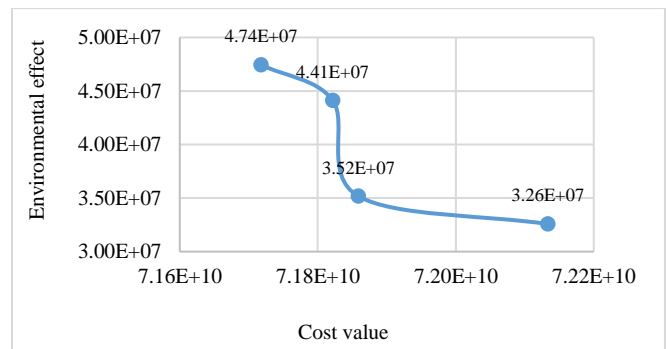
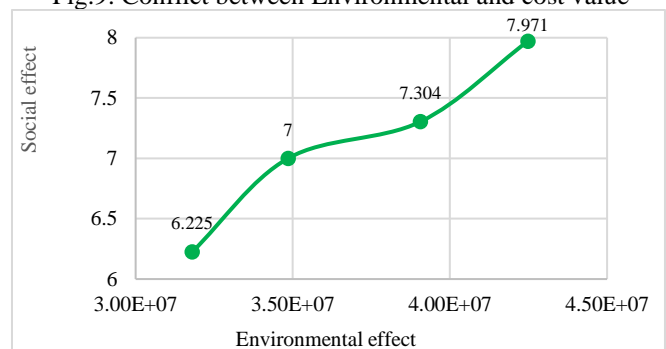
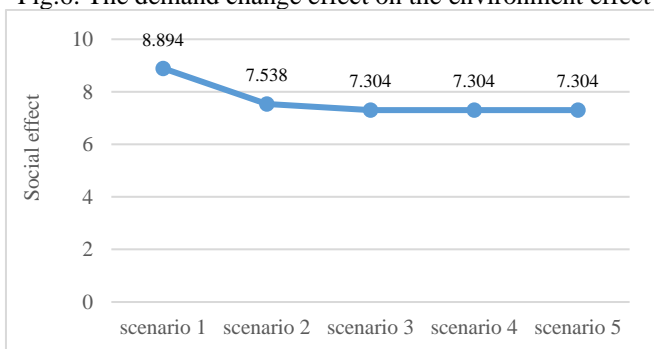


Fig.9. Conflict between Environmental and cost value



6.3. Sensitivity analysis of cost parameters

In this section, the model's behavior is investigated concerning changes in the model's costs. To determine the impact of various operational costs, including production cost, raw material purchase cost, transportation cost, inventory maintenance cost, and human labor cost, on the total costs of SCN design, these costs were increased by 10% in the each iteration. The impact of these cost changes on the entire chain's costs was investigated. The results can be seen in Fig.11. According to this figure, changing the slope of the values, it can be stated that the change in the costs of production and purchase of raw materials has the most significant impact on the costs of the entire chain. Therefore, it is better to focus on reducing production costs and purchasing raw materials to reduce costs. It should be noted that since the change in other costs, such as the cost of wastewater treatment and freshwater supply, had minimal effect compared to the changes in other costs, their effects have been omitted in this chart.

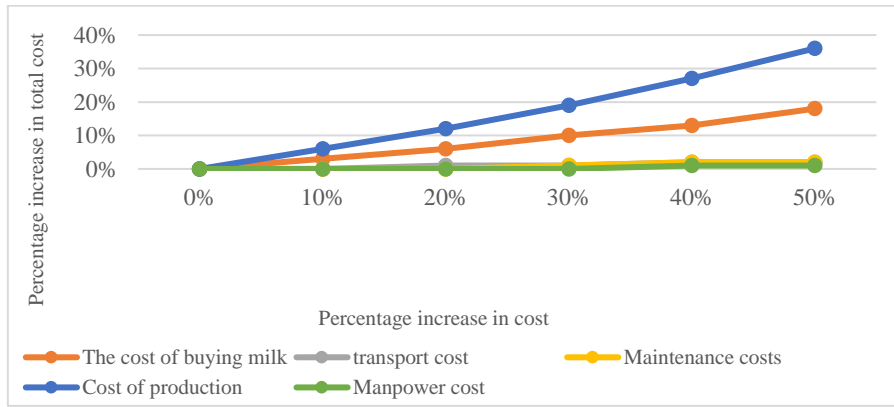


Fig.11. Sensitivity analysis of cost parameters

6.4. Validation of stochastic problem

In this section we use the expected value of perfect information (EVPI) and value of the stochastic solution (VSS) concepts to validate stochastic solutions. The EVPI estimates the maximum amount a decision maker would be ready to pay in return for complete information in the future. Originally, it represents the loss of profit due to the presence of uncertainty and is defined in the form of equation (23). The VSS index is defined as equation (24), and the other concept is VSS, which can be used to find out whether putting extra effort into modeling and solving stochastic programming is beneficial. In fact, a higher VSS points out the advantages of using a stochastic programming approach. Note that it is not equal to the expected value of perfect information and may be larger than the EVPI (Tikani et al. 2018).

$$EVPI = Z_{HN} - Z_{WS} \tag{23}$$

$$VSS = Z_{EEV} - Z_{HN} \tag{24}$$

The EVPI and VSS indexes are calculated in Tables 7 and 8, respectively. The EVPI in Table 7 implies that future information for this case can be bought up to about 4.05995×10^8 units of cost. Also, the value obtained for VSS is a large number that shows how much the objective function is improved if stochastic programming is used. According to the value obtained for VSS, this model's use of random programming is justified.

Table.7. Result outputs of models solve approach

Approach	Information	Expected Profit
Z _{HN}	Stochastic	7.73E+10
Z _{EEV}	Expected	7.76E+10
Z _{WS}	Perfect	7.69E+10

Table.8. Proposed model validation test

INDEX	Measurement	Value
EVPI	7.73E+10-7.69E+10	4.06E+8
VSS	7.76E+10- 7.73E+10	3.20E+8

7. Discussion and managerial insights

The current situation of the dairy manufacturer consists of one manufacture and three distribution centers. The economic, environmental, and social objective functions equal 7.94E+10, 4.99E+7, and 6.317, respectively. The company plans to build at least one manufacturer and one distribution center in other parts of the country to gain market share. The experts determined the proposed locations, and the economic, environmental, and social objective function values obtained were 7.73E+10, 4.71E+7, and 6.225, respectively. According to Fig.12, the proposed model shows a 3% cost improvement, equivalent to a cost reduction of 21,000,000,000 Rials, and a 6% reduction in environmental effects, equivalent to 2,800,000 units per m3. Therefore, the proposed model is not only justified in terms of reasonable costs and environmental impact compared to the current state, but it also demonstrates the financial viability of the proposed changes.

It's important to note that when the current locations of the clean manufacturer and distribution centers were considered candidate points, only the construction of a distribution center was proposed. This indicates the need for a proactive redesign of the current state of the clean manufacturer to better align with our expansion plans. According to the above notions, the managerial results can be explained as follows:

- The strategic decision to build a manufacturer Isfahan province and a distribution center in Ahvaz is in line with the dairy manufacturer's plan to expand its market share. Isfahan's proximity to milk production centers and Ahvaz's higher unemployment rate compared to other candidate places make them ideal locations for our expansion.
- The proposed model addresses the issue of products' non-perishability in the facility's warehouse by setting a limit on the maximum allowed amount of product inventory based on perishability.
- The results suggest that the manufacturer is deeply committed to investing in reducing the environmental effects caused by transportation and in reducing water consumption through wastewater treatment. This unwavering commitment is demonstrated by our plan to use means of transportation that produce fewer pollutants and to implement a treatment plant that can treat wastewater for reuse. If the government provides subsidies for environmental protection, part of the manufacturer's costs could be covered, further reinforcing our commitment to sustainability.

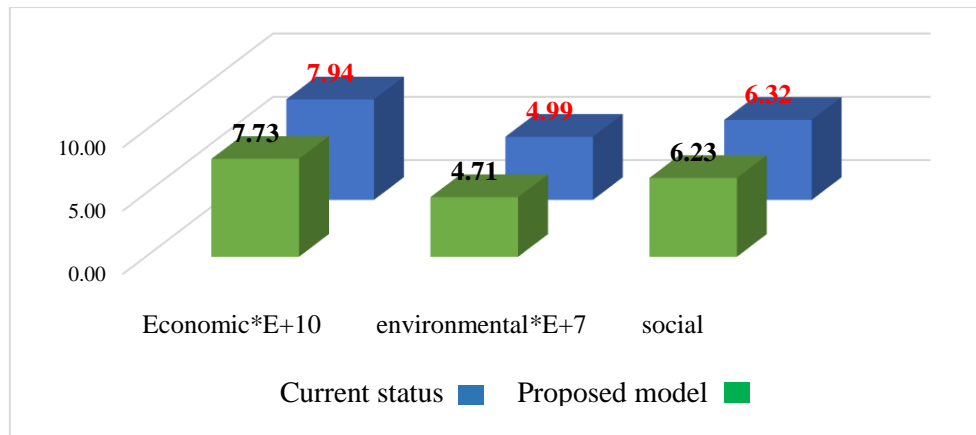


Fig.12. Comparison of the current conditions of the case study with the result of proposed model

8. Conclusions

This article discusses the design of supply networks for edible nutrients under conditions of stability and non-sustainability. The model considers the perspectives of producers, production centers, and customers and enables the direct or indirect transportation of goods from manufacturer centers to customers. The model is presented as multi-objective perturbed integer programming, with the first objective being cost minimization, which includes investment costs, raw material purchase costs, production costs, transportation costs, maintenance costs, manpower costs, and wastewater filter preparation. The second objective is to minimize greenhouse gas emissions, which include carbon dioxide emissions from new storage locations, inventory, and transportation between different levels. The third objective is to maximize the social accountability of the supply chain, including job creation and health and safety during the COVID-19 pandemic. The model also accounts for epidemic diseases, which cause uncertainty and can be controlled through scenario-based stochastic programming. The proposed model was solved using GAMS software and CPLEX solver and was validated using EVPI and VSS indices. The model's effectiveness was investigated using data from a case study of a "dairy manufacturer" in Iran. The analysis showed that considering wastewater and reusing treated water improves network costs and that the costs of raw materials have the most significant impact on the costs of the entire chain. Pareto maps were used to investigate conflicts between goals, and it was found that the objective functions conflicted with each other. Finally, the logistics network of the case study was compared to the proposed conditions, which included the construction of a manufacturer among three candidate regions and a center among four suggested points based on expert opinions and geographical locations. Compared to the existing conditions of the manufacturer, the proposed conditions resulted in a 3% reduction in costs and a 6% reduction in environmental effects. These results demonstrate the model's effectiveness and support the construction of a manufacturer and center in the proposed regions for the future program of the study under consideration. The following suggestions can be considered in future research:

- Considering disruptions in suppliers or manufacturers
- Considering routing issues and their integration into the network design
- The use of exact solution methods, such as Bander's decomposition algorithm

Reference

Abbasi S, Saboury A, Jabalameli MS. Reliable supply chain network design for 3PL providers using consolidation hubs under disruption risks considering product perishability: An application to a pharmaceutical distribution network. *Computers & Industrial Engineering*. 2021 Feb 1;152:107019.

- Alkaabneh F, Diabat A, Gao HO. Benders decomposition for the inventory vehicle routing problem with perishable products and environmental costs. *Computers & Operations Research*. 2020 Jan 1;113:104751.
- Askary M, Makui A, Tajik M. A robust multi-objective MIP model to optimize the supply chain of steel industry taking into account the sustainability approach. *RAIRO-Operations Research*. 2024 Mar 1;58(2):1059-91.
- Carter CR, Rogers DS. A framework of sustainable supply chain management: moving toward new theory. *International journal of physical distribution & logistics management*. 2008 Jun 13;38(5):360-87.
- Farahani RZ, Hekmatfar M, editors. *Facility location: concepts, models, algorithms and case studies*. Springer Science & Business Media; 2009 Jul 9.
- Galindres LF, Guimarães FG, Gallego-Rendón RA. Multi-objective sustainable capacitated location routing problem formulation in sustainable supply-chain management. *Engineering Optimization*. 2023 Mar 4;55(3):526-41.
- Govindan K, Jafarian A, Nourbakhsh V. Designing a sustainable supply chain network integrated with vehicle routing: A comparison of hybrid swarm intelligence metaheuristics. *Computers & operations research*. 2019 Oct 1;110:220-35.
- Govindan K. Sustainable consumption and production in the food supply chain: A conceptual framework. *International Journal of Production Economics*. 2018 Jan 1;195:419-31.
- Goyal SK, Giri BC. Recent trends in modeling of deteriorating inventory. *European Journal of operational research*. 2001 Oct 1;134(1):1-6.
- Ho W, Zheng T, Yildiz H, Talluri S. Supply chain risk management: a literature review. *International journal of production research*. 2015 Aug 18;53(16):5031-69.
- Mentzer JT, DeWitt W, Keebler JS, Min S, Nix NW, Smith CD, Zacharia ZG. Defining supply chain management. *Journal of Business logistics*. 2001 Sep;22(2):1-25.
- Mogale DG, Cheikhrouhou N, Tiwari MK. Modelling of sustainable food grain supply chain distribution system: a bi-objective approach. *International Journal of Production Research*. 2020 Sep 16;58(18):5521-44.
- Mohammadi Z, Barzinpour F, Teimoury E. A location-inventory model for the sustainable supply chain of perishable products based on pricing and replenishment decisions: A case study. *PloS one*. 2023 Jul 31;18(7):e0288915.
- Mohammed A, Wang Q. The fuzzy multi-objective distribution planner for a green meat supply chain. *International journal of production economics*. 2017 Feb 1;184:47-58.
- Movahed, A. B., Movahed, A. B., & Nozari, H. (2024). Opportunities and challenges of marketing 5.0. *Smart and sustainable interactive marketing*, 1-21.
- Mula J, Poler R, Garcia JP. MRP with flexible constraints: A fuzzy mathematical programming approach. *Fuzzy sets and systems*. 2006 Jan 1;157(1):74-97.
- Mulvey JM, Vanderbei RJ, Zenios SA. Robust optimization of large-scale systems. *Operations research*. 1995 Apr;43(2):264-81.
- Musavi M, Bozorgi-Amiri A. A multi-objective sustainable hub location-scheduling problem for perishable food supply chain. *Computers & Industrial Engineering*. 2017 Nov 1;113:766-78.

- Nasiri MM, Khaleghi A, Govindan K, Bozorgi-Amiri A. Sustainable hierarchical multi-modal hub network design problem: bi-objective formulations and solution algorithms. *Operational Research*. 2023 Jun;23(2):35.
- Nurjanni KP, Carvalho MS, Costa L. Green supply chain design: A mathematical modeling approach based on a multi-objective optimization model. *International journal of production economics*. 2017 Jan 1;183:421-32.
- Rad RS, Nahavandi N. A novel multi-objective optimization model for integrated problem of green closed loop supply chain network design and quantity discount. *Journal of cleaner production*. 2018 Sep 20;196:1549-65.
- Rahimi M, Ghezavati V, Asadi F. A stochastic risk-averse sustainable supply chain network design problem with quantity discount considering multiple sources of uncertainty. *Computers & Industrial Engineering*. 2019 Apr 1;130:430-49.
- Sazvar Z, Rahmani M, Govindan K. A sustainable supply chain for organic, conventional agro-food products: The role of demand substitution, climate change and public health. *Journal of cleaner production*. 2018 Sep 1;194:564-83.
- Shen ZM, Sun Y. Strengthening supply chain resilience during COVID-19: A case study of JD. com. *Journal of Operations Management*. 2023 Apr;69(3):359-83.
- Singh N, Tang Y, Zhang Z, Zheng C. COVID-19 waste management: Effective and successful measures in Wuhan, China. *Resources, conservation, and recycling*. 2020 Dec;163:105071.
- Tang CS. Perspectives in supply chain risk management. *International journal of production economics*. 2006 Oct 1;103(2):451-88.
- Tikani H, Honarvar M, Zare Mehrjerdi Y. Two-stage stochastic programming model for capacitated complete star p-hub network with different fare classes of customers. *Journal of Industrial and Systems Engineering*. 2018 Mar 31;11(1):74-96.
- Tsao YC, Thanh VV, Lu JC, Yu V. Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming. *Journal of Cleaner Production*. 2018 Feb 10;174:1550-65.
- Yakavenka V, Mallidis I, Vlachos D, Iakovou E, Eleni Z. Development of a multi-objective model for the design of sustainable supply chains: The case of perishable food products. *Annals of Operations Research*. 2020 Nov;294:593-621.
- Yigit F, Esnaf S. A novel model for the calculation of safety stock of perishable products with a total waste constraint. *International Journal of Industrial Engineering*. 2023 Mar 1;30(2).
- Zhu X, Wen Z, Regan D, Zhu J. A systematic analysis of supply chain risk management literature: 2012-2021. *International Journal of Industrial Engineering: Theory, Applications and Practice*. 2023 Nov 16;31(3).