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Green reverse supply chain management with location-routing- inventory decisions with simultaneous pickup and delivery

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Abstract
The consideration reverse flows in the supply chain management is highly attended recently. The supply chain network (SCN) design for the reverse logistics leads to a high interest in environmentalism and sustainability. Moreover, an efficient SCN must made decisions on vehicle routing with pickup and delivery, location of centers, and inventory status in addition to the goals of the cost reduction and greenness of the SCN. With an introduction of the perishable products, the design of green reverse SCN and the mentioned decisions as a location-routing-inventory model is contributed to this research. The proposed model minimizes the total costs of chain and lost demands simultaneously and uses a fuzzy multi-objective solution approach. As far as we know, the concepts of reverse supply chain with location-routing-inventory model and simultaneous consideration of pickup and delivery activities have been used for perishable products among the first studies. The proposed model's efficiency has been assessed using a bread production and distribution chain in Alborz province. Finally, the results show that the proposed model is applicable and efficient for the presented case study.

Keywords
Green reverse supply chain network; Inventory-location-routing decision; Pickup and delivery; Uncertainty

1. Introduction

These days, a large number of companies attempt to boost their business activities in the world so that they can fulfill customer needs and reach customer satisfaction (Fathollahi-Fard et al., 2020a). In this way, they can survive and compete in the highly competitive setting. In this course, the

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management of supply chains is in the works as a very important challenge among the industry owners and scientific researchers (Ramezani et al., 2014; Kannan et al., 2020). The starting point of these issues is the procurement of raw materials that concludes with the satisfaction of customer demands via the desirable delivery of the completed products (Fathollahi-Fard et al., 2020b). The design of supply chain networks (SCNs) comes into play as a critical planning activity and is considered as a background problematic issue of managing supply chains that may affect one supply chain for a couple of years (Melo et al., 2009). Recently, the development of environmental rules and awareness as well as reduced pollution and customer pressure have all shifted attentions to such issues as green manufacturing and remanufacturing, reverse logistic, and waste management, which are regarded as the important subordinates of green supply chain management. It should be mentioned that green supply chain management is referred to as the combination of environmental criteria and supply chain management that entail different items like delivery processes, production, satisfaction of customer demands, end of life management of used products, and materials procurement (Rad and Nahavandi, 2018). Although this misconception is still at play among some managers and decision makers that the implementation of green supply chain processes is costly, there are sufficient valid reasons for its cost-effectiveness. It has been scientifically and practically proven that the implementation of a green supply chain may impose some costs on the chain in the short run, whereas it will lead to a reduction in costs in the long run (Gholipour et al., 2020). The consideration of both forward and reverse flows in the design of SCNs is one of the practices that can lead to the design of a green supply chain (Govindan et al., 2015). This is so because the volume of disposal products and resources consumption decreases in reverse supply chains due to the reuse/ recycling of returned products, which can to the mitigation of destructive environmental effects (Mardan et al., 2019). It is also highly important to consider the location-routing problem in the design of SCNs, especially the green supply chain. In fact, the optimal location of facilities, proper routing, and optimal schedule for vehicles towards service delivery to customers not only reduce the costs, but also reduce the harmful effects of the environment and protection of the environment due to the reduction of vehicle fuel consumption (Qazvini et al., 2019). Upon raising the issue of products' perishability, the importance of this issue will be multiplied since the improper location of facilities and non-optimal routing may perish the products in addition to increasing the costs and destructive effects on the environment. This, in turn, results in the disruption of demand response, supply reduction, increased price of products, increased costs of the chain, and destruction of the environment (Liu et al., 2020); and, consequently, the destruction of consumer resources, energy, and so on may occur (Eftekhari et al., 2020).

With the increasing rate of population, the demand for food products is growing rapidly. Societies have already come to the understanding that human responsibilities, such as food production impose some demands on the nature and environment (Miranda-Ackerman et al., 2017). In this regard, Vermeulen et al. (2012) report that 19% to 29% of global greenhouse gases emissions are rooted in agricultural activities and the food production system (Yu et al., 2021). As a perishable item, bread is one of the most important products of wheat that constitutes the main food of people in the world and has been included in the household food basket as a basic product. According to the statistics released by the Food and Agriculture Organization (FAO), the wheat consumption per capita in Iran is about 160 (kg/year), which is about three times larger than the global average (www.fao.org). Moreover, according to a report presented by the Ministry of Industry, Mine and Trade, the per capita consumption of bread in Iran is about 150 (kg/year), while the global average is less than 60 (kg/year) (www.mimt.gov.ir). Findings show that a significant part of this perishable product is exposed to disposal due to the mismanagement of this chain. Therefore, the design of a SCN for the production management, distribution, and reuse of bread can reduce chain costs and disposal products. In addition, the CO2 emission can be reduced since wheat production and CO2 emissions have a direct relationship with each other. In Figure 1, the amount of wheat production in Iran has been illustrated from 2010 to 2018, and Figure 2 shows CO2 emissions from wheat production from 2011 to 2017.

Considering these points, this paper aims at designing a green reverse SCN for perishable products, especially bread. The intended network is a multi-product and multi-echelon one and there is the possibility of the product return from the retailer. To overcome this issue, the concept of simultaneous pickup and delivery is used in the vehicle routing problem (VRP) in such a way that the heterogeneous vehicles heading towards retailers from distribution centers pick up the returned products at the same time with the product delivery to retailers. In doing so, a bi-objective mixed-integer linear programming (MILP) model is employed to develop a green SCN for the management of production, distribution, and waste reduction by considering both forward and reverse flows. It is noteworthy that the problem under study includes inventory-location-routing problem, supplier selection, vehicular schedule, and soft and hard time windows. In order to evaluate the efficiency of the proposed model, the data of a bread production industry in Iran are used. This paper is intended to address the following questions:

a. What is an effective model for integrating inventory-location-routing problem with simultaneous pickup and delivery, and vehicle scheduling in a green SCN?
b. What is a practical method for solving the proposed multi-objective model under uncertainty?
c. What is a reasonably effective method for validating the applicability of the model?

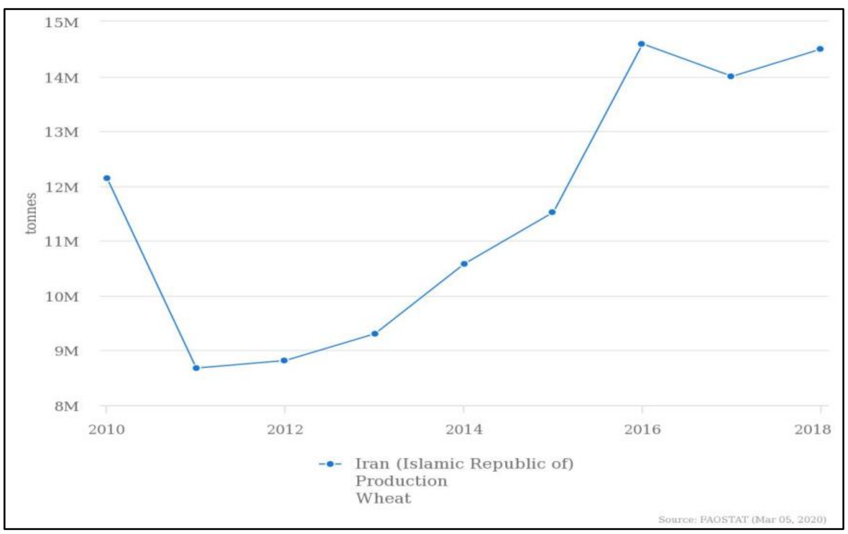

Fig.1. Amount of wheat production per 1000 tones unit

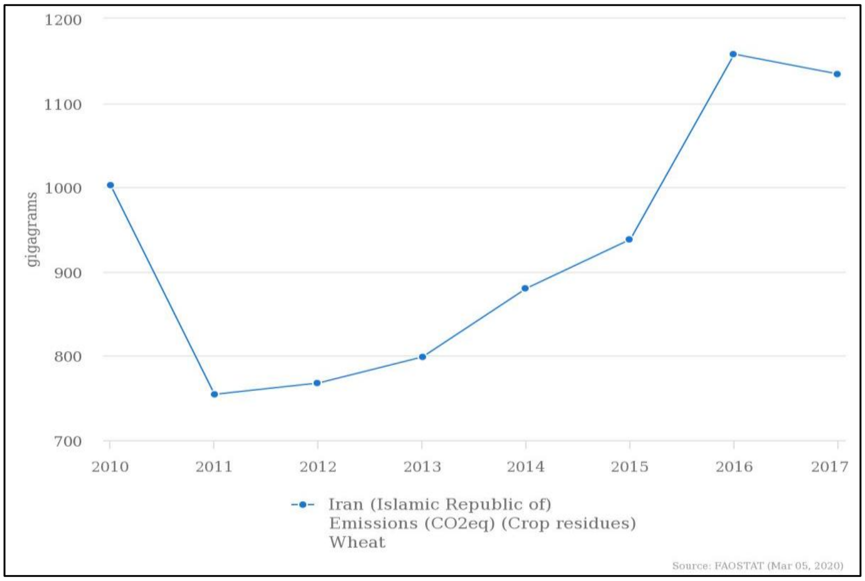

Fig.2. Amount of CO2 emission resulting from wheat production per gigagrams unit

2. Literature review

This study seeks to design a green reverse SCN for perishable products by considering the VRP with simultaneous pickup and delivery and the assumptions of time window, location, lost demand, uncertainty, and storage for future periods. Up to our knowledge with a reference to Table 1, the literature review of this article is concentrated on two categories of studies as no study has previously taken into consideration all of these assumptions at once. The first category consists of the papers that include green reverse supply chain with at least one of the above assumptions. The second one encompasses the studies that include pickup and delivery problem and at least one of the above assumptions. Reverse SCN refers to a network that entails both forward and reverse flows (Govindan et al., 2020). Forward flow aims to deliver the final products from the first level of the chain to customers, while the reverse flow includes the levels of collection, recycling, and disposal, which vary in different chains and are dependent on the industry under study (Mardan et al., 2019). There are a large number of studies in the field of reverse SCN design and some of them are discussed below (Fathollahi-Fard et al., 2020c; 2020d; 2020e; Hajiaghaei-Keshteli et al., 2019).

In this domain, a bi-objective MILP model with the aim of minimizing total costs and destructive environmental effects was proposed by Mardan et al. (2019) to design a green closed-loop supply chain network (CLSCN). The location of the centers was among the strategic decisions of this model whose efficiency was assessed using the data of a cable-and-wire industry in Iran. Yavari and Zaker (2019) also developed a bi-objective MILP model for the design of a resilient green CLSCN for perishable products. They considered inventory-location problem in their model and tried to minimize the total cost and pollution emission. In a similar study, Yavari and Geraeli (2019) used an MILP model to develop a green CLSCN. Their model focuses on the simultaneous minimization of total cost and pollution emission. They utilized a robust optimization method to consider uncertainty and, eventually, used a heuristic method to solve the proposed model. Sadeghi et al. (2020) used a MILP model to design a multi-product and multi-period green CLSCN. The location and routing of centers by means of heterogeneous vehicles constituted the important decisions of their model. In fact, this model minimizes the total cost of the chain and makes use of the data of an automotive parts industry for the validation purpose. In the same vein, Govindan et al. (2020) suggested a new concept, entitled circular CLSCN where they proposed an MILP model. The model aimed to minimize the total cost and lost sales at the same time wherein a fuzzy approach has been used to solve the proposed bi-objective model.

Now, it is turn to the review of the literature related to the field of pickup and delivery with at least one of the above assumptions in order to identify the other dimensions of the problem under study. These titles are structurally very similar to the main problem, but their details vary. This problem was first proposed by Wilson et al. (1976) under the title of dial-a-ride problem. To date, the pickup and delivery problem has been used in wide range of areas with different assumptions. Abraham et al. (2012) used a VRP with the pickup and delivery to optimize a SCN for perishable products in the air-cargo industry. Their model aims to minimize costs in a certain time window in order to deliver services the chain. A VRP with pickup and delivery considering pollution emission and time window with uncertain input data was proposed by Tajik et al. (2014) for the first time. They used a MILP model for this purpose. This model aimed at minimizing the fuel consumption and greenhouse gas emissions in the form of costs in addition to minimizing the distance and number of vehicles. Also, in this model, the robust optimization approach was employed to consider uncertainty in the problem. Wang et al. (2015a) developed a simulated annealing method algorithm to solve VRP with pickup and delivery considering time window with the aim of minimizing the routing costs, including vehicle and travel costs. Avci and Topaloglu (2016) took a step further and introduced a meta-heuristic algorithm for solving VRP with pickup and delivery by using heterogeneous vehicles. Yu and Lin (2016) then added the location problem to the VRP with pickup and delivery and proposed a problem with the aim of minimizing the building facilities costs, vehicle costs, and travel costs. A MILP model was also developed by Komijan and Delavari (2017) with the aim of minimizing total cost in order to structure a perishable SCN. In addition to considering the pickup and delivery problem, they also included the scheduling of vehicles and time window in their model. Thereafter, Soleimani et al. (2018) proposed a bi-objective MILP model which aimed at minimizing vehicle emissions and minimizing total costs for designing a green SCN considering VRP with pickup and delivery. They benefited from a fuzzy approach to solve their bi-objective model and used the data of a newspaper distribution system in Iran to validate their model. Similarly, a VRP with pickup and delivery was proposed by Ahkamiraad and Wang (2018) by considering the multiple cross-docking problem and time window. In this regard, they made use of a hybrid approach based on genetic algorithm and particle swarm optimization to solve their problem. Nadizadeh and Kafash (2019) developed a mathematical model in order to minimize the routing costs, start-up costs, and vehicle costs by considering the location-routing problem with pickup and delivery under uncertain conditions. In recent years, the integration of the pickup and delivery problem with practical assumptions has received considerable attention. For example, this problem has been considered in combination with the location problem by Capelle et al. (2019) and Azizi and Hu (2020). In the same way, Navazi et al. (2019) have considered the assumptions of perishability and location problem in the pickup and delivery problem. The differences and similarities between the problem in this study and those in the literature are shown in Table 1; moreover, the research gaps have been well presented in this table.

Table (1): The literature focusing on pickup and delivery problem and green reverse logistics

Author(s)	Year	Model type	Network structure			Facilities location	Routing problem	Inventory planning	Heterogeneous vehicles	Pickup and delivery	Time window	Environmental impacts	perishability	Uncertainty
			Multi-product	Multi-period	Reverse									
Abraham et al.	2012	MILP model	-	-	-	-	*	-	-	*	*	-	*	-
Govindan et al.	2014	MOMILP model	-	*	-	*	*	*	*	-	*	*	*	-
Wang et al.	2015a	MILP model	-	-	-	-	*	-	-	*	*	-	-	-
Wang et al.	2015b	MOMILP model	-	-	-	-	*	-	-	*	*	-	-	-
Yu and Lin	2016	MILP model	-	-	-	*	*	-	-	*	-	-	-	-
Song and Ko	2016	MINLP model	*	-	-	-	*	-	*	-	-	-	*	-
Avci and Topaloglu	2016	MILP model	-	-	-	-	*	-	*	*	-	-	-	-
Zhalechian et al.	2016	MOMINLP model	*	*	*	*	*	*	*	-	-	*	-	*
Kuo and Nugroho	2017	MILP model	*	-	-	-	*	-	*	-	*	-	*	*
Rabbani et al.	2017	MILP model	*	*	-	-	*	*	*	-	-	*	*	-
Fang et al.	2017	MILP model	-	*	-	-	*	*	-	*	-	*	-	-
Komijan and Delavari	2017	MILP model	*	*	-	-	*	*	*	*	*	-	*	-
Iassinovskaia et al.	2017	MILP model	-	*	*	-	*	*	-	*	*	-	-	-
Vahdani et al.	2017	MILP model	*	*	-	-	*	*	*	-	*	*	*	*
Soysal et al.	2018	MILP model	*	*	-	-	*	*	-	*	-	*	*	*
Sahraeian and Esmaeili	2018	MOMILP model	-	-	-	*	*	-	*	-	*	*	*	-
Ahkamiraad and Wang	2018	MILP model	-	-	-	*	*	-	-	*	*	-	-	-
Soleimani et al.	2018	MOMILP model	*	-	-	*	*	-	*	*	-	*	-	*
Ghomi and Asgarian	2019	MILP model	-	*	-	*	*	*	-	-	-	-	*	-
Rahbari	2019	MOMILP model	*	-	-	*	*	*	*	-	*	-	*	*
Navazi et al.	2019	MOMILP model	-	*	-	*	*	-	-	*	-	*	*	-
Golsefidi and Jokar	2020	MILP model	-	*	-	-	*	*	-	*	-	-	-	*
Abdi et al.	2020	MOMILP model	*	*	-	-	*	*	*	*	-	*	-	-
Zulvia et al.	2020	MOMINLP model	*	*	-	-	*	-	*	-	*	*	*	*
Biuki et al.	2020	MOMILP model	*	*	-	*	*	*	*	-	-	*	*	*
This paper		**MOMILP model**	*	*	*	*	*	*	*	*	*	*	*	*

MILP: Mixed-integer linear programming; MINLP: Mixed-integer nonlinear programming; MO: Multi-objective

3. Proposed problem

In this paper, a multi-product, multi-period, and multi-echelon green reverse SCN including suppliers, production and separation centers, retailers, drying centers, disposal centers, and livestock feed markets, is designed for perishable products (see Figure. 3). In the intended chain, the production center purchases the raw material (flour) from suppliers and delivers the product (bread) to retailers after its production using optimal vehicle routing and scheduling and, simultaneously, pick up the returned products. Then, the returned products are inspected at separation centers and those that are usable as livestock feed are sent to drying centers and the remainder are transferred to disposal centers.

In the drying center, the products are processed and the final processed products are sold to livestock feed markets. In order to explain the chain in more detail, the problem assumptions are presented below:

- Except the location of retailers and suppliers, other centers are located by the proposed model.
- The routing problem is of a capacitated and multi-depot type, in which the possibility of split-delivery has been considered.
- The possibility of simultaneous pickup and delivery has been considered in the routing problem.
- Routing is carried out by heterogeneous vehicles and is considered between production centers and retailers points.
- There is the possibility of product storage in warehouses of retailers.
- Shortage has been considered as lost demand.
- Lifetime has been defined for products to take perishability into account.
- Suppliers, all centers, and vehicles are capacitated.
- Both soft and hard time windows have been included in the chain design.

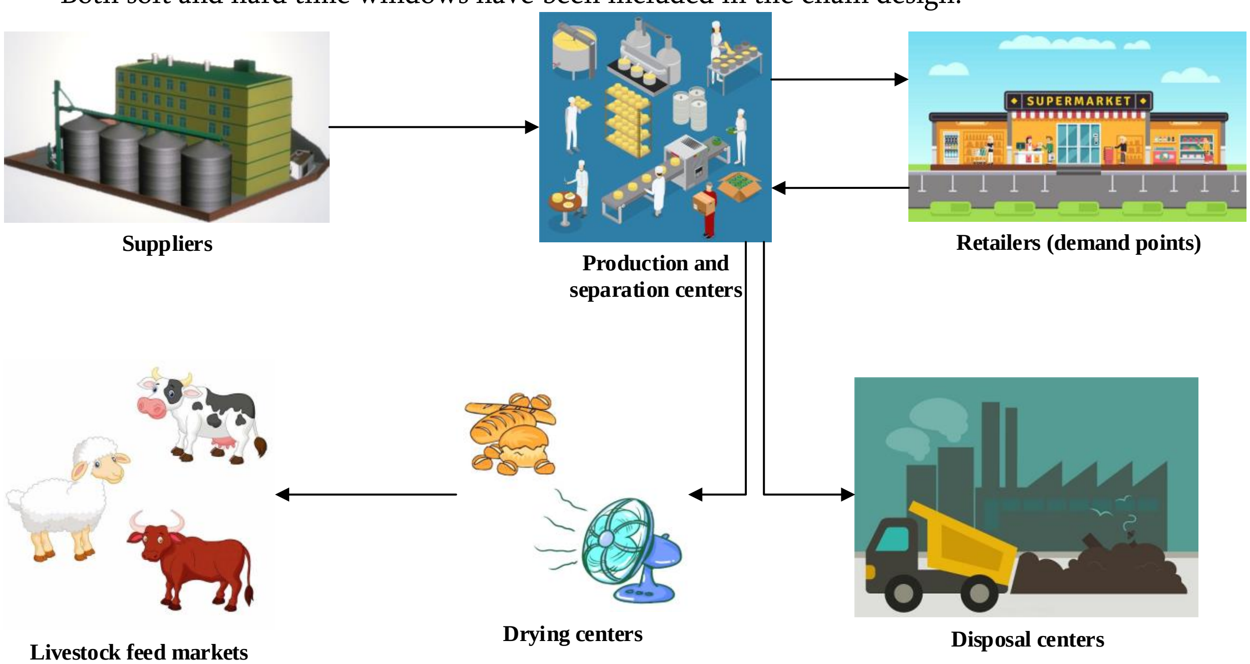

Fig.3. The structure of under study SCN

Objective functions

$$Min\ Z_1 = \sum_{r,f,t} F\alpha_{ft} \times Y\alpha_{rft} + \sum_{b} F\beta_b \times Y\beta_b + \sum_{k,b,c} V\beta_{kbc} \times Y'\beta_{kbc} + \sum_{i} F\mu_i \times Y\mu_i + \sum_{j} F\theta_j \times Y\theta_j + \sum_{p} F\varphi_p \times Y\varphi_p + \sum_{r,f,b,t} X\alpha\beta_{rfbt} \times \alpha\beta_{rfbt} + \sum_{r,f,b,t} P\alpha_{rft} \times X\alpha\beta_{rfbt} + \sum_{k,p,b,m,t} P\beta_{kbt} \times X\beta\delta_{kpbmt} + \sum_{k,m,t} P\delta^{+}_{kmt} \times \eta^{+}_{kmt} + \sum_{k,m,t} P\delta^{-}_{kmt} \times \eta^{-}_{kmt} + \sum_{k,p,m,b,t} P\beta'_{kbt} \times X\delta\beta_{kpmbt} + \sum_{k,b,i,t} P\mu_{kit} \times X\beta\mu_{kbit} + \sum_{k,b,j,t} P\theta_{kjt} \times X\beta\theta_{kbjt} + \sum_{k,b,i,t} \beta\mu_{kbit} \times X\beta\mu_{kbit} + \sum_{k,b,j,t} \beta\theta_{kbjt} \times X\beta\theta_{kbjt} + \sum_{i,l,t} \mu\xi_{ilt} \times X\mu\xi_{ilt} + P\varphi \times \sum_{p,m>1,n>1,t} \varphi_p \times \delta_{mn} \times Y_{pmnt} + P\varphi \times \sum_{p,b,m>1,t} \varphi_p \times \beta\delta_{bm} \times X_{pb} \times (Y_{p1mt} + Y_{pm1t}) + E\varphi \times \sum_{p,m>1,n>1,t} \varphi_p \times \delta_{mn} \times Y_{pmnt} + E\varphi \times \sum_{p,b,m>1,t} \varphi_p \times \beta\delta_{bm} \times X_{pb} \times (Y_{p1mt} + Y_{pm1t}) + \sum_{p,m,t} PP \times \lambda P_{pmt} - \sum_{i,l,t} P\xi_{lt} \times X\mu\xi_{ilt} \qquad (1)$$

$$Min\ Z_2 = \sum_{k,m,t} \eta^{-}_{kmt} \qquad (2)$$

Subjected to:

$$\sum_{f} X\alpha\beta_{rfbt} \geq \varpi_{rk} \times \sum_{p,m} X\beta\delta_{kpbmt} \qquad \forall r,k,b,t \qquad (3)$$

$$\eta_{kmt} = \sum_{p,b} X\beta\delta_{kpbmt} - C\delta_{kmt} - R\delta_{kmt} \qquad \forall k,m,t=1 \qquad (4)$$

$$\eta_{kmt} = \eta^{+}_{km(t-1)} + \sum_{p,b} X\beta\delta_{kpbmt} - C\delta_{kmt} - R\delta_{kmt} \qquad \forall k,m,t>1 \qquad (5)$$

$$\eta_{kmt} = \eta^{+}_{kmt} - \eta^{-}_{kmt} \qquad \forall k,m,t \qquad (6)$$

$$X\delta\beta_{kpmbt} \geq R\delta_{kmt} \times X\beta\delta_{kpbmt} \qquad \forall k,p,b,m,t \qquad (7)$$

$$X\delta\beta_{kpmbt} \leq R\delta_{kmt} \times X\beta\delta_{kpbmt} + 1 \qquad \forall k,p,b,m,t \qquad (8)$$

$$\sum_{p,m} X\delta\beta_{kpmbt} = \sum_{i} X\beta\mu_{kbit} + \sum_{j} X\beta\theta_{kbjt} \qquad \forall k,b,t \qquad (9)$$

$$\sum_{i} X\beta\mu_{kbit} = PR_{kbt} \times \sum_{p,m} X\delta\beta_{kpmbt} \qquad \forall k,b,t \qquad (10)$$

$$\sum_{l} X\mu\xi_{ilt} = \sum_{k,b} KG_k \times X\beta\mu_{kbit} \qquad \forall i,t \qquad (11)$$

$$\eta_{kmt} \leq \sum_{t'=t}^{t+LT_k} C\delta_{kmt'} \qquad \forall k,m,t \leq T - LT_k \qquad (12)$$

$$\eta_{kmt} \leq \sum_{t'=t}^{T} C\delta_{kmt'} \qquad \forall k,m,t > T - LT_k \qquad (13)$$

$$\lambda T_{pnt} + BM \times (1 - Y_{pmnt}) \geq \lambda T_{pmt} + TS_{pm} + T\delta_{pmn} \qquad \forall p,m,n>1,t \qquad (14)$$

$$TWF + BM \times (1 - Y_{pm1t}) \geq \lambda T_{pmt} + TS_{pm} + T\beta\delta_{pbm} \times X_{pb} \qquad \forall p,b,m>1,t \qquad (15)$$

$$\lambda T_{pmt} \geq TW^{-}_{mt} \qquad \forall p,m,t \qquad (16)$$

$$\lambda T_{pmt} - TW^{+}_{mt} \le \lambda P_{pmt} \qquad \forall p,m,t \qquad (17)$$

$$\lambda T_{pmt} - \lambda T_{qmt} + BM \times Z_{pqmt} \ge TS_{qm} \qquad \forall p \ne q, m>1, t \qquad (18)$$

$$\lambda T_{qmt} - \lambda T_{pmt} + BM \times (1 - Z_{pqmt}) \ge TS_{pm} \qquad \forall p \ne q, m>1, t \qquad (19)$$

$$\sum_{p,m} X\beta\delta_{kpbmt} + BM \times (1 - Y'\beta_{kbc}) > C\beta^{-}_{kbc} \qquad \forall k,b,c,t \qquad (20)$$

$$\sum_{p,m} X\beta\delta_{kpbmt} \le BM \times (1 - Y'\beta_{kbc}) + C\beta^{+}_{kbc} \qquad \forall k,b,c,t \qquad (21)$$

$$\sum_{b} X\alpha\beta_{rfbt} \le C\alpha_{rft} \qquad \forall r,f,t \qquad (22)$$

$$\sum_{k,p,m} X\delta\beta_{kpmbt} \times VL_k \le C\beta_{bt} \qquad \forall b,t \qquad (23)$$

$$\sum_{k,b} X\beta\mu_{kbit} \times VL_k \le C\mu_{it} \qquad \forall i,t \qquad (24)$$

$$\sum_{k,b} X\beta\theta_{kbjt} \times VL_k \le C\theta_{jt} \qquad \forall j,t \qquad (25)$$

$$\sum_{i} X\mu\xi_{ilt} \le C\xi_{lt} \qquad \forall l,t \qquad (26)$$

$$DLV_{kpmt} + BM \times (1 - Y_{pmnt}) \ge DLV_{kpnt} + X\beta\delta_{kpbnt} \qquad \forall k,p,b,m,n>1,t \qquad (27)$$

$$DLV_{kp1t} \ge \sum_{m} X\beta\delta_{kpbmt} \qquad \forall k,p,b,t \qquad (28)$$

$$PCK_{kpnt} + BM \times (1 - Y_{pmnt}) \ge PCK_{kpmt} + X\delta\beta_{kpmbt} \qquad \forall k,p,b,m,n>1,t \qquad (29)$$

$$PCK_{kp1t} \ge \sum_{m} X\delta\beta_{kpmbt} \qquad \forall k,p,b,t \qquad (30)$$

$$\sum_{k} DLV_{kpmt} \times VL_k + \sum_{k} PCK_{kpmt} \times VL_k + \sum_{k} X\beta\delta_{kpbmt} \times VL_k \le C\varphi_p \qquad \forall p,b,m>1,t \qquad (31)$$

$$\sum_{k} DLV_{kpmt} \times VL_k + \sum_{k} PCK_{kpmt} \times VL_k + \sum_{k} X\delta\beta_{kpmbt} \times VL_k \le C\varphi_p \qquad \forall p,b,m>1,t \qquad (32)$$

$$\sum_{k} DLV_{kpmt} \times VL_k + \le C\varphi_p \qquad \forall p,m=1,t \qquad (33)$$

$$\sum_{k} PCK_{kpmt} \times VL_k \le C\varphi_p \qquad \forall p,m=1,t \qquad (34)$$

$$\sum_{m} Y_{pmnt} \le 1 \qquad \forall p,n,t \qquad (35)$$

$$\sum_{m} Y_{pmnt} - \sum_{m} Y_{pnmt} = 0 \qquad \forall p,n,t \qquad (36)$$

$$X\beta\delta_{kpbnt} \le BM \times \sum_{m} Y_{pmnt} \qquad \forall k,p,b,n,t \qquad (37)$$

$$X\delta\beta_{kpnbt} \le BM \times \sum_{m} Y_{pmnt} \qquad \forall k,p,n,b,t \qquad (38)$$

$$X\beta\delta_{kpbnt} \le BM \times Y\varphi_p \qquad \forall k,p,b,n,t \qquad (39)$$

$$X\delta\beta_{kpnbt} \le BM \times Y\varphi_p \qquad \forall k,p,n,b,t \qquad (40)$$

$$X\beta\delta_{kpbnt} \le BM \times X_{pb} \qquad \forall k,p,b,n,t \qquad (41)$$

$$X\delta\beta_{kpnbt} \le BM \times X_{pb} \qquad \forall k,p,n,b,t \qquad (42)$$

$$\sum_{b} X_{pb} \le 1 \qquad \forall p \qquad (43)$$

$$Y'\beta_{kbc} \leq BM \times Y\beta_b \qquad \forall k,b,c \tag{44}$$

$$\sum_p X_{pb} \leq BM \times \sum_{k,c} Y'\beta_{kbc} \qquad \forall b \tag{45}$$

$$\sum_c Y'\beta_{kbc} \leq 1 \qquad \forall k,b \tag{46}$$

$$X\alpha\beta_{rfbt} \leq BM \times Y\alpha_{rft} \qquad \forall r,f,b,t \tag{47}$$

$$X\alpha\beta_{rfbt} \leq BM \times \sum_c Y'\beta_{kbc} \qquad \forall r,k,f,b,t \tag{48}$$

$$X\beta\delta_{kpbmt} \leq BM \times \sum_c Y'\beta_{kbc} \qquad \forall k,p,b,m,t \tag{49}$$

$$X\delta\beta_{kpmbt} \leq BM \times \sum_c Y'\beta_{kbc} \qquad \forall k,p,m,b,t \tag{50}$$

$$X\beta\mu_{kbit} \leq BM \times \sum_c Y'\beta_{kbc} \qquad \forall k,b,i,t \tag{51}$$

$$X\beta\theta_{kbjt} \leq BM \times \sum_c Y'\beta_{kbc} \qquad \forall k,b,j,t \tag{52}$$

$$X\beta\mu_{kbit} \leq BM \times Y\mu_i \qquad \forall k,b,i,t \tag{53}$$

$$X\mu\xi_{ilt} \leq BM \times Y\mu_i \qquad \forall l,i,t \tag{54}$$

$$X\beta\theta_{kbjt} \leq BM \times Y\theta_j \qquad \forall k,b,j,t \tag{55}$$

The first objective function embarks on minimizing the total costs of the chain. The costs are as follows: Cost of ordering to suppliers, setting up cost of production centers with different capacity levels, setting up cost of drying centers, setting up cost of disposal centers, cost of purchasing vehicles, the cost paid for the transport of raw materials, purchase cost of raw materials from suppliers, manufacturing cost of products in production centers, holding cost of products in retailers' warehouses, shortage cost, separation cost of products in separation centers, processing and drying cost of products in drying centers, removal cost of products in disposal centers, transportation cost of products between chain levels, fuel consumption cost by vehicles, cost of greenhouse gas emission (environmental degradation) arising from fuel consumption by vehicles, violation cost of time window, and revenue from the sale of processed products in the livestock feed market, which is reduced from costs.

The second objective function aims at minimizing the lost demands.

Constraint (3) controls the inventory balance in production centers. In fact, the amount of raw material purchased from suppliers should not be less than the amount of product transferred from production centers to retailers. The inventory balance in retailers' warehouses is given in constraints (4) and (5) for the first period and subsequent periods, respectively. Constraint (6) indicates the relationship between inventory level, lost demand, and amount of storage. The amount of product returned from retailers to the separation centers is calculated by constraints (7) and (8). The inventory balance in separation centers has been considered in constraint (9). Constraint (10) calculates the amount of product transferred from separation centers to bread drying center. The amount of product transferred from bread drying centers to the livestock feed market is calculated by constraint (11). Determining the inventory level to prevent products from perishing is controlled by constraints (12) and (13). Sub-tour elimination is guaranteed by constraints (14) and (15). Moreover, constraint (15) guarantees not exceeding the hard time window. The control of the lower bound of the time window is considered by constraint (16) while constraint (17) indicates the amount of exceeding from the present time window. Constraint's (18) and (19) manage vehicle schedules on retailer visits. Determining the level of production capacity is considered by constraints (20) and (21). Non-exceeding the capacity of suppliers, separation centers, reuse centers, and disposal centers is given in constraints (22) to (25), respectively. Each livestock feed market purchases the processed products at most up to its capacity where this capacity constraint is controlled by constraint (26). The amount of deliverable products available in vehicles when exiting the retailers is calculated by constraints (27) and (28). The amount of returned products existing in vehicles is calculated by constraints (29) and (30) before arrival to the retailers' location. Constraints (31) to (34) guarantee that no vehicle capacity is exceeded. In each time period, each vehicle is allowed to visit each retailer at most once. It should be noted that it is possible for each retailer to be visited by more than one vehicle at any given time period. This possibility is represented by constraint (35). Constraint (36) states that if a vehicle enters a retailer's location, it must leave there after service delivery to it. The condition for the delivery of products to retailers and pickup of the returned products from retailers is that the vehicle has visited the retailers. This condition has been considered in constraints (37) and (38), respectively. The other condition for product delivery to retailers and the pickup of returned products from them is that the vehicle has been purchased, which is shown in constraints (39) and (40), respectively. The assigning of the purchased vehicle to a production center is another condition for product delivery to retailers and pickup of returned products from them, which is represented in constraints (41) and (42), respectively. Constraint (43) ensures that each vehicle should be allocated at most to one production center. The condition for the installation of machines in a production center is that the production center should have already been set up. This condition is met by constraint (44). If the production center has not been set up yet, no vehicle should be allocated to it; this condition is satisfied by constraint (45). Constraint (46) argues that at most one machine (production capacity level) can be used to produce each product in each production center. The condition for the purchase of raw materials from suppliers is that orders should be placed to suppliers; indeed, constraint (47) reflects this condition. Based on the location conditions, if a center has not been set up, it is not allowed to provide any service. This condition is given in constraints (48) to (52) for production and separation centers. In addition, this condition is also considered for bread drying centers in constraints (53) and (54) and for disposal centers in constraint (55).

3.1. Linearization process

In the proposed model, the term $Y_{pmnt} \times X_{pb}$ in the first objective function has made it nonlinear. For this purpose, XY_{pbmnt} is defined as a new binary variable and replaces the nonlinear term in the first objective function as follows:

$$\begin{aligned}
Min\ Z_1 = & \sum_{r,f,t} F\alpha_{ft} \times Y\alpha_{rft} + \sum_{b} F\beta_b \times Y\beta_b + \sum_{k,b,c} V\beta_{kbc} \times Y'\beta_{kbc} + \\
& \sum_{i} F\mu_i \times Y\mu_i + \sum_{j} F\theta_j \times Y\theta_j + \sum_{p} F\varphi_p \times Y\varphi_p + \sum_{r,f,b,t} X\alpha\beta_{rfbt} \times \alpha\beta_{rfbt} + \\
& \sum_{r,f,b,t} P\alpha_{rft} \times X\alpha\beta_{rfbt} + \sum_{k,p,b,m,t} P\beta_{kbt} \times X\beta\delta_{kpbmt} + \sum_{k,m,t} P\delta^{+}_{kmt} \times \eta^{+}_{kmt} + \\
& \sum_{k,m,t} P\delta^{-}_{kmt} \times \eta^{-}_{kmt} + \sum_{k,p,m,b,t} P\beta'_{kbt} \times X\delta\beta_{kpmbt} + \sum_{k,b,i,t} P\mu_{kit} \times X\beta\mu_{kbit} + \\
& \sum_{k,b,j,t} P\theta_{kjt} \times X\beta\theta_{kbjt} + \sum_{k,b,i,t} \beta\mu_{kbit} \times X\beta\mu_{kbit} + \sum_{k,b,j,t} \beta\theta_{kbjt} \times X\beta\theta_{kbjt} + \\
& \sum_{i,l,t} \mu\xi_{ilt} \times X\mu\xi_{ilt} + P\varphi \times \sum_{p,m>1,n>1,t} \varphi_p \times \delta_{mn} \times Y_{pmnt} + \\
& P\varphi \times \sum_{p,b,m>1,t} \varphi_p \times \beta\delta_{bm} \times (XY_{pb1mt} + XY_{pbm1t}) + E\varphi \times \sum_{p,m>1,n>1,t} \varphi_p \times \delta_{mn} \times Y_{pmnt} + \\
& E\varphi \times \sum_{p,b,m>1,t} \varphi_p \times \beta\delta_{bm} \times X_{pb} \times (Y_{p1mt} + Y_{pm1t}) + \sum_{p,m,t} PP \times \lambda P_{pmt} - \sum_{i,l,t} P\xi_{lt} \times X\mu\xi_{ilt}
\end{aligned} \tag{56}$$

Then, the relationship between the two binary variables of Y_{pmnt} and X_{pb}, and the new binary variable is stated as follows:

$$XY_{pbmnt} \le Y_{pmnt} + BM \times (1 - X_{pb}) \tag{57}$$

$$XY_{pbmnt} \le X_{pb} + BM \times (1 - Y_{pmnt}) \tag{58}$$

$$XY_{pbmnt} \ge 1 + BM \times (X_{pb} + Y_{pmnt} - 2) \tag{59}$$

$$XY_{pbmnt} \le BM \times (X_{pb} + Y_{pmnt}) \tag{60}$$

Thus, the first linearized objective (i.e., Eq. 56) replaces Eq. 1; and Eqs 57 to 60 are added to the constraints of the proposed model.

3.2. Multi-objective solution approach

The fuzzy multi-objective solution proposed by Tavana et al. (2020) is used. The proposed approach consists of two phases, as follows:

- Phase I: First, the proposed bi-objective is converted to a single objective model by means of the fuzzy solution approach presented by Zimmermann (1978).

$$\begin{aligned}
& Max\ \omega \\
& St: \\
& \omega \le \psi_{Z_g^{Min}} \\
& \omega \le \psi_{Z_h^{Max}} \\
& System\ constraints
\end{aligned} \tag{61}$$

where $\psi_{Z_h^{Max}}$ and $\psi_{Z_g^{Min}}$ indicate the membership functions for minimization and maximization objective functions, respectively and this proposition holds true: $\omega = Min\left\{\psi_{Z_g^{Min}}, \psi_{Z_h^{Max}}\right\}$. The system constraints also represent the constraints of the proposed model (i.e. constrains (3) to (55) and constraints (57) to (60)). The membership functions are defined as follows:

$$\psi_{Z_g^{Min}} = \begin{cases} 1 & Z_g > Z_g^+ \\ 0 & Z_g < Z_g^- \\ \dfrac{Z_g^+ - Z_g}{Z_g^+ - Z_g^-} & Z_g^- \leq Z_g \leq Z_g^+ \end{cases}$$

$$\psi_{Z_h^{Max}} = \begin{cases} 1 & Z_h > Z_h^+ \\ 0 & Z_h < Z_h^- \\ \dfrac{Z_h^+ - Z_h}{Z_h^+ - Z_h^-} & Z_h^- \leq Z_h \leq Z_h^+ \end{cases}$$

where Z_g^- and Z_g^+ respectively denote the lower and upper bounds of the minimization objective functions; and Z_h^- and Z_h^+ indicate the lower and upper bounds of the maximization objective functions, respectively. By running the proposed model in GAMS software, the optimal value of ω (i.e. ω^*) is obtained.

- Phase II: In this phase, ω^* obtained from phase I is used to develop a weighted fuzzy solution approach presented by Tavana et al. (2020) in order to solve the bi-objective model. This weighted fuzzy solution is as follows:

$$\begin{aligned} & Max\ \bar{\omega} = \sum_g w_g \times \omega_g + \sum_h w_h \times \omega_h \\ & St: \\ & \omega^* \leq \omega_g \leq \psi_{Z_g^{Min}} \\ & \omega^* \leq \omega_h \leq \psi_{Z_h^{Max}} \\ & \sum_g w_g + \sum_h w_h = 1 \\ & System\ constraints \end{aligned} \tag{62}$$

where w_g indicates the importance of the *g*th minimization objective function and w_h represents the importance of the *h*th maximization objective function. In addition, these corresponding values are determined by experts.

4. Case study

In this section, the data of a bread production-distribution chain in Karaj, Alborz Province are used in order to validate the proposed model. Karaj is the fourth metropolis in Iran, located 40 km northwest of Tehran (i.e., the capital of Iran). The current chain produces and supplies two types of products, namely bulky bread and flat bread, while flour is considered the main raw material in the production of these products. The flour required for the chain is usually purchased from four potential suppliers, namely Seifabad, Mahdasht, Varamin, and Robatkarim. In this regard, three areas around the city of Karaj, including Hashtgerd, Nazarabad, and Baharestan have been considered as the potential production and separation centers and 10 heterogeneous vehicles are available to distribute products among retailers. In addition, 6 areas in Karaj have been selected as retailers' demand points, whose geographical locations are shown in Figure 3. It should be noted that each area consists of several retailers (i.e., supermarkets), and the total demand of retailers in each area has been considered as the demand point. The distribution of bread at the specified points takes place twice a week, while the time horizon in this study has been considered to be four time periods (2 weeks). It should also be mentioned that the lifetime of products is one week (i.e., 2 time periods). The following presents a summary of some data of the intended chain in Tables 2 to 7.

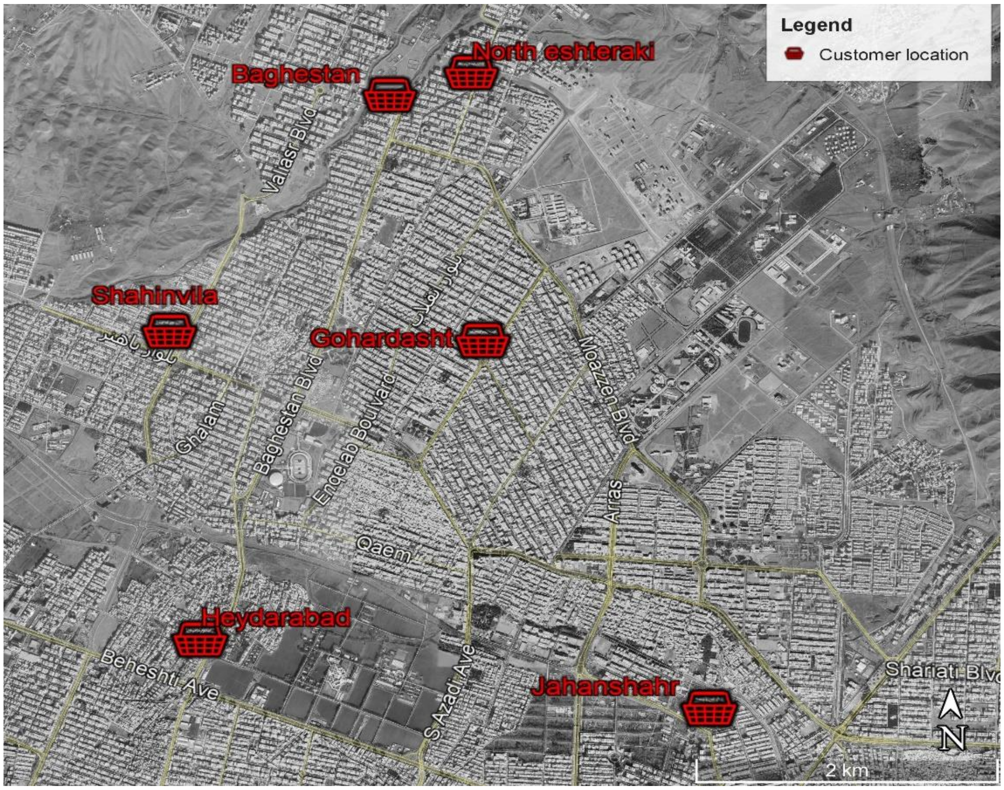

Fig. 3. The geographical location of demand points (retailers)

Table (2): The demand of retailers

$C\delta_{kmt}$		$t=1$	$t=2$	$t=3$	$t=4$
$k=1$	$m=1$ (Productioncenter)	0	0	0	0
$k=1$	$m=2$ (Jahanshahr)	227	272	245	246
$k=1$	$m=3$ (Gohardasht)	267	305	255	248
$k=1$	$m=4$ (Baghestan)	221	246	258	230
$k=1$	$m=5$ (North Eshteraki)	215	214	245	218
$k=1$	$m=6$ (Shahinvila)	297	337	319	291
$k=1$	$m=7$ (Heydarabad)	183	212	218	192
$k=2$	$m=1$ (Productioncenter)	0	0	0	0
$k=2$	$m=2$ (Jahanshahr)	158	155	145	151
$k=2$	$m=3$ (Gohardasht)	167	195	157	194
$k=2$	$m=4$ (Baghestan)	136	151	155	131
$k=2$	$m=5$ (North Eshteraki)	141	157	150	160

$k=2$	$m=6$ (Shahinvila)	138	146	130	157
$k=2$	$m=7$ (Heydarabad)	148	146	154	123

The retailer 1 (m=1) is the production center

Table (3): The capacity of suppliers (bag)

	$C\alpha_{rft}$	$t=1$	$t=2$	$t=3$	$t=4$
$r=1$	$f=1$ (Seifabad)	120	120	120	120
$r=1$	$f=2$ (Mahdasht)	100	100	100	100
$r=1$	$f=3$ (Varamin)	150	150	150	150
$r=1$	$f=4$ (Robatkarim)	120	120	120	120

The weight of each bag = 40000 grams

Table(4): The maximum production capacity for each production level (package)

	$C\beta^{+}_{kbc}$	$c=1$	$c=2$
$k=1$	$b=1$ (Hashtgerd)	40000	60000
$k=1$	$b=2$ (Nazarabad)	40000	60000
$k=1$	$b=3$ (Baharestan)	40000	60000
$k=2$	$b=1$ (Hashtgerd)	36000	50000
$k=2$	$b=2$ (Nazarabad)	36000	50000
$k=2$	$b=3$ (Baharestan)	36000	50000

The weight of each package = 330 grams

Table (5): The distance among retailers (km)

δ_{mn}	$n=1$	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
$m=1$	0	45.5	43.9	44.5	45.3	32.5	31.6
$m=2$	45.5	0	5.1	7	6.1	7.2	4.5
$m=3$	43.9	5.1	0	3.1	2.9	4	3.8
$m=4$	44.5	7	3.1	0	1.5	5.3	5.9
$m=5$	45.3	6.1	2.9	1.5	0	6.7	6
$m=6$	32.5	7.2	4	5.3	6.7	0	5.2
$m=7$	31.6	4.5	3.8	5.9	6	5.2	0

Table(6): The distance among retailers and production centers (km)

$\beta\delta_{bm}$	$m=1$	$m=2$	$m=3$	$m=4$	$m=5$	$m=6$	$m=7$
$b=1$	0	36.9	35.4	36	36.8	32.5	31.6
$b=2$	0	45.5	43.9	44.5	45.3	41.1	40.2
$b=3$	0	16.6	13.1	12.8	14.1	9.3	11.3

Table (7): The capacity, supplying cost, and fuel consumption of vehicles

	$C\varphi_p(m^3)$	$F\varphi_p(Toman)$	$\varphi_p(liter/km)$
$p=1$	6.5	90,000,000	0.17
$p=2$	6.5	90,000,000	0.17
$p=3$	6.5	90,000,000	0.17
$p=4$	8	85,000,000	0.21
$p=5$	8	85,000,000	0.21
$p=6$	8	85,000,000	0.21
$p=7$	8.5	94,000,000	0.23
$p=8$	8.5	94,000,000	0.23
$p=9$	8.5	94,000,000	0.23
$p=10$	8.5	94,000,000	0.23

4.1. Implementation of multi-objective solution approach

A the multi-objective solution approach presented by Tavana et al. (2020) is used here to transform the model into a single objective form and the case study data are given as follows:

- Phase I: For this purpose, the lower and upper bounds of the objective functions should be first determined. To obtain the lower bound of the first objective function and the upper bound of the second objective function, the proposed model should be run corresponding to the first objective function (regardless of the second objective function). In addition, the proposed model should be run corresponding to the second objective function (regardless of the first objective function) to calculate the upper bound of the first objective function and the lower bound of the second objective function. The lower bound of the second objective function is always equal to zero and occurs when there is no lost demand in any time period. However, the upper bound of the second objective function occurs when all retailer demands remain unanswered in all time periods. In other words, the sum of retailer demands in all time periods (i.e. $\sum_{k,m,t} C\delta_{kmt}$) is considered as the upper bound of the second objective function. Accordingly, the membership functions for the first and second objective functions are as follows:

$$\psi_{Z_g^{Min}} = \frac{Z_1^+ - Z_1}{Z_1^+ - Z_1^-} = \frac{5,766,825,742 - Z_1}{5,766,825,742 - 381,353,000} = \frac{5,766,825,742 - Z_1}{5,385,472,742}$$

$$\psi_{Z_h^{Max}} = \frac{Z_2^+ - Z_2}{Z_2^+ - Z_2^-} = \frac{9606 - Z_1}{9606}$$

Therefore, based on the solution approach presented by Zimmermann (1978), the bi-objective model is converted into the following:

$$Max\ \omega$$
$$St:$$
$$\omega \le \frac{5,766,825,742 - Z_1}{5,385,472,742}$$
$$\omega \le \frac{9,606 - Z_2}{9,606}$$
$$Constraints\ (3)-(55)\ and\ (57)-(60)$$

By running the obtained model in GAMS software using CPLEX solver, the optimal value of ω (i.e. ω^*) is calculated, which is equal to 0.687.

- Phase II: In this phase, the proposed bi-objective model is converted into the following single objective one (values of w_1 and w_2 have been considered 0.6 and 0.4, respectively) by using ω^* obtained from phase I and the weighted fuzzy solution approach presented by Tavana et al. (2020):

$$Max\ \bar{\omega} = 0.6 \times \omega_1 + 0.4 \times \omega_2$$
$$St:$$
$$0.687 \le \omega_1 \le \frac{5,766,825,742 - Z_1}{5,385,472,742}$$
$$0.687 \le \omega_2 \le \frac{9,606 - Z_2}{9,606}$$
$$Constraints\ (3)-(55)\ and\ (57)-(60)$$

4.2. Results and discussion

Running the single objective model in GAMS software using CPLEX solver, one can obtain the optimal values as follows:

- The optimal value of the first objective function equals 2,065,461,653 tomans and the optimal value of the second objective function is 2869, i.e. being faced with a total of 2869 units of lost demands in 4 time periods.
- Raw materials (flour) should be purchased from supplier 1 (i.e. Seifabad) in time periods 1, 2, and 4 and from supplier 2 (i.e. Mahdasht) in time period 3.
- Production center 1 (i.e. Hashtgerd) should be set up with capacity level 1 to produce both types of products.
- Drying center 2 and disposal center 1 should be set up.
- Vehicles 2, 3, 4, 9, and 10 should be purchased and assigned to production center 1.
- The routes that each vehicle should travel in each time period (sequence of visiting the retailer) are shown in Table 8.

Table (8): Sequence of visits paid to retailers for each vehicle in each time period

$p=2$	$t=3$	**Hashtgerd→ Baghestan→ Jahanshahr→ Gohardasht→ Shahinvila→ Hashtgerd**
	$t=4$	Hashtgerd→ Shahinvila→ Heydarabad→ Jahanshahr→ North Eshteraki→ Baghestan→ Hashtgerd
$p=3$	$t=1$	Hashtgerd→ Shahinvila→ North Eshteraki→ Gohardasht→ Heydarabad→ Jahanshahr→ Hashtgerd
	$t=2$	Hashtgerd→ Baghestan→ North Eshteraki→ Shahinvila→ Gohardasht→ Jahanshahr→ Heydarabad→ Hashtgerd
	$t=3$	Hashtgerd→ Shahinvila→ Baghestan→ North Eshteraki→ Gohardasht→ Heydarabad→ Jahanshahr→ Hashtgerd
$p=4$	$t=1$	Hashtgerd→ Gohardasht→ Jahanshahr→ Heydarabad→ Shahinvila→ North Eshteraki→ Baghestan→ Hashtgerd
	$t=2$	Hashtgerd→ Shahinvila→ Gohardasht→ Heydarabad→ Hashtgerd
	$t=3$	Hashtgerd→ Gohardasht→ Jahanshahr→ Hashtgerd
	$t=4$	Hashtgerd→ North Eshteraki→ Shahinvila→ Hashtgerd
$p=9$	$t=1$	Hashtgerd→ Heydarabad→ Shahinvila→ Jahanshahr→ Hashtgerd
	$t=2$	Hashtgerd→ Jahanshahr→ Baghestan→ Hashtgerd
	$t=3$	Hashtgerd→ Jahanshahr→ Heydarabad→ Shahinvila→ Gohardasht→ North Eshteraki→ Baghestan→ Hashtgerd
	$t=4$	Hashtgerd→ North Eshteraki→ Gohardasht→ Hashtgerd
$p=10$	$t=1$	Hashtgerd→ Shahinvila→ Gohardasht→ North Eshteraki→ Baghestan→ Hashtgerd
	$t=2$	Hashtgerd→ Baghestan→ North Eshteraki→ Shahinvila→ Gohardasht→ Jahanshahr→ Hashtgerd
	$t=3$	Hashtgerd→ Heydarabad→ Shahinvila→ North Eshteraki→ Hashtgerd
	$t=4$	Hashtgerd→ Jahanshahr→ North Eshteraki→ Hashtgerd

The routes traveled by each vehicle in each time period are shown in Table 8. For example, vehicle 2 moves from production center 1 (Hashtgerd) to retailer 4 (Baghestan) in time period 3. After service delivery to this retailer, it visits retailer 2 (Jahanshahr), retailer 3 (Gohardasht), and retailer 6 (Shahinvila), respectively. It eventually returns to production center 1. As it was mentioned earlier, vehicles 2, 3, 4, 9, and 10 should be used to provide service for retailers; indeed, the results presented in Table 8 confirm this statement. It is also noteworthy that the scheduling of vehicles has also been considered in this study in addition to their optimal routing. Therefore, the time interference between vehicles in service delivery to retailers is reduced although the consideration of the constraints pertaining to vehicle scheduling may result in an increase in the distance traveled by vehicles. The results presented in Table 8 show that the least time interference between vehicles has occurred in service delivery to retailers in addition to optimal routing.

The number of flour bags purchased from each supplier is shown in Table 9. The results presented in Table 9 indicate that the required flour has been supplied from suppliers 1 and 2. For example, 24 flour bags have been purchased from supplier 1 by production center 1 in time period 1.

Table (9): The number of flour bags purchased from suppliers in each time period

$X\alpha\beta_{rfbt}$			$t=1$	$t=2$	$t=3$	$t=4$
$r=1$	$f=1$	$b=1$	24	7	0	4
$r=1$	$f=2$	$b=1$	0	0	16	0

The amount of products delivered to each retailer and the amount of products picked up by each retailer are reported in Tables 10 and 11, respectively. For example, number 327 in the first row of Table 10 indicates that vehicle 2 has delivered 327 units of product 1 to retailer 6 (Shahinvila) in time period 4. Similarly, number 36 in the first row of Table 11 shows that the intended vehicle has picked up 36 units of the returned product from the same retailer in the same time period. Therefore, the operation conducted on retailer 6 by vehicle 2 in time period 4 can be interpreted in this way that this retailer has received 327 units of product 1 in this time period, has used 291 units as demand, and has returned 36 units to separation center 1. As it can be observed in Table 2, retailer 6 has demanded 291 units of product 1 in time period 4, which is confirmed by the obtained results. In the same way, the accuracy of the results obtained for other retailers can be checked in all time periods. In addition, as it can be seen, vehicles 2, 3, 4, 9, and 10 have been all used to deliver products to retailers and pick up products from them and all of these vehicles have been allocated to production center 1 (Hashtgerd). These results are fully in line with the results obtained for the binary variables described above.

Table (10): Amount of products delivered to retailers by each vehicle in each time period

$X\beta\delta_{kpbmt}$				$t=1$	$t=2$	$t=3$	$t=4$
$k=1$	$p=2$	$b=1$	$m=6$	0	0	0	327
$k=1$	$p=3$	$b=1$	$m=2$	469	0	0	0
$k=1$	$p=3$	$b=1$	$m=4$	49	0	0	0
$k=1$	$p=3$	$b=1$	$m=5$	9	0	423	0
$k=1$	$p=3$	$b=1$	$m=6$	73	0	192	0
$k=1$	$p=4$	$b=1$	$m=2$	0	0	241	0
$k=1$	$p=4$	$b=1$	$m=3$	0	0	510	0
$k=1$	$p=4$	$b=1$	$m=4$	197	0	0	0
$k=1$	$p=4$	$b=1$	$m=5$	453	0	0	72
$k=1$	$p=4$	$b=1$	$m=6$	88	91	0	0
$k=1$	$p=9$	$b=1$	$m=2$	359	0	0	0
$k=1$	$p=9$	$b=1$	$m=3$	0	0	0	22
$k=1$	$p=9$	$b=1$	$m=4$	0	775	0	0
$k=1$	$p=9$	$b=1$	$m=7$	429	0	0	0
$k=1$	$p=10$	$b=1$	$m=3$	303	0	0	0
$k=1$	$p=10$	$b=1$	$m=6$	460	0	146	0
$k=1$	$p=10$	$b=1$	$m=7$	0	0	447	0
$k=2$	$p=2$	$b=1$	$m=3$	0	0	120	0
$k=2$	$p=2$	$b=1$	$m=5$	0	0	0	42
$k=2$	$p=3$	$b=1$	$m=7$	0	117	0	0
$k=2$	$p=4$	$b=1$	$m=5$	0	0	0	133
$k=2$	$p=4$	$b=1$	$m=6$	0	130	0	0
$k=2$	$p=9$	$b=1$	$m=2$	0	0	161	0
$k=2$	$p=9$	$b=1$	$m=3$	0	0	0	151
$k=2$	$p=9$	$b=1$	$m=4$	0	5	0	0
$k=2$	$p=10$	$b=1$	$m=2$	0	0	0	155
$k=2$	$p=10$	$b=1$	$m=6$	0	159	0	0

Table (11): The amount of product pickup from retailers by each vehicle in each time period

$X\delta\beta_{kpmbt}$				$t=1$	$t=2$	$t=3$	$t=4$
$k=1$	$p=2$	$m=6$	$b=1$	0	0	0	36
$k=1$	$p=3$	$m=2$	$b=1$	36	0	0	0
$k=1$	$p=3$	$m=4$	$b=1$	5	0	0	0
$k=1$	$p=3$	$m=5$	$b=1$	1	0	24	0
$k=1$	$p=3$	$m=6$	$b=1$	8	0	11	0
$k=1$	$p=4$	$m=2$	$b=1$	0	0	16	0
$k=1$	$p=4$	$m=3$	$b=1$	0	0	27	0
$k=1$	$p=4$	$m=4$	$b=1$	20	0	0	0
$k=1$	$p=4$	$m=5$	$b=1$	32	0	0	8
$k=1$	$p=4$	$m=6$	$b=1$	10	10	0	0
$k=1$	$p=9$	$m=2$	$b=1$	27	0	0	0
$k=1$	$p=9$	$m=3$	$b=1$	0	0	0	2
$k=1$	$p=9$	$m=4$	$b=1$	0	41	0	0
$k=1$	$p=9$	$m=7$	$b=1$	34	0	0	0
$k=1$	$p=10$	$m=3$	$b=1$	36	0	0	0
$k=1$	$p=10$	$m=6$	$b=1$	50	0	8	0
$k=1$	$p=10$	$m=7$	$b=1$	0	0	37	0
$k=2$	$p=2$	$m=3$	$b=1$	0	0	10	0
$k=2$	$p=2$	$m=5$	$b=1$	0	0	0	4
$k=2$	$p=3$	$m=7$	$b=1$	0	13	0	0
$k=2$	$p=4$	$m=5$	$b=1$	0	0	0	11
$k=2$	$p=4$	$m=6$	$b=1$	0	9	0	0
$k=2$	$p=9$	$m=2$	$b=1$	0	0	9	0
$k=2$	$p=9$	$m=3$	$b=1$	0	0	0	13
$k=2$	$p=9$	$m=4$	$b=1$	0	1	0	0
$k=2$	$p=10$	$m=2$	$b=1$	0	0	0	11
$k=2$	$p=10$	$m=6$	$b=1$	0	11	0	0

The amount of products stored in warehouses of retailers and the amount of lost sales in each time period are presented in Tables 12 and 13, respectively. The results in Table 12 demonstrate that storage has occurred in all time periods except time period 4. This occurrence indicates that the model function is logical because storage always occurs for future periods and no storage should occur during period 4, i.e. the last period. The number 538 shown in the first row of Table 12 represents that 538 units of product 1 have been stored in the warehouse of retailer 2 at the end of time period 1. According to the results presented in Table 10, vehicles 3 and 9 have respectively delivered 469 and 359 units of product 1 to retailer 2 in time period 1. In other words, these two vehicles have delivered a total of 828 units of product 1 to this retailer. On the other hand, the results presented in Table 11 show that vehicles 3 and 9 have picked up 36 and 27 units of product 1 from the mentioned retailer in time period 1 (63 units of product 1 have been totally picked up from the retailer). The data presented in Table 2 also state that the retailer has demanded 227 units of product 1 in time period 1. From the available information, it can be concluded that a total of 828 units of product 1 have been delivered to retailer 2 in time period 1, the intended retailer has consumed 227 units of it as demand, 63 units have been returned to separation center 1, and 538 units has been stored in stock. Therefore, number 538 shown in the first row of Table 12 has been obtained as follows.

Table (12): Amount of products stored at warehouses of retailers in each time period

η^{+}_{kmt}		$t=1$	$t=2$	$t=3$
$k=1$	$m=2$	538	266	246
$k=1$	$m=3$	0	0	228
$k=1$	$m=4$	0	488	230
$k=1$	$m=5$	214	0	154
$k=1$	$m=6$	256	0	0
$k=1$	$m=7$	212	0	192
$k=2$	$m=2$	0	0	7
$k=2$	$m=6$	0	123	0

Table (13): Amount of lost sales in each time period

η^{+}_{kmt}		$t=1$	$t=2$	$t=3$	$t=4$
$k=1$	$m=3$	0	305	0	0
$k=2$	$m=2$	158	155	0	0
$k=2$	$m=3$	167	195	47	56
$k=2$	$m=4$	136	147	155	131
$k=2$	$m=5$	141	157	150	0
$k=2$	$m=6$	138	0	7	157
$k=2$	$m=7$	148	42	154	123

The analysis of the obtained results showed that there is a logical relationship between the parameters and decision variables of the proposed model, which confirms the efficiency and effectiveness of the proposed model. However, it is worthy of mentioning that the implementation of the proposed model with $w_1 = 0.6$ and $w_2 = 0.4$ led to the shortage of 2869 units; in other words, remained unsatisfied. In order to survive in the competitive market and take the lead from other competitors, many companies today try hard to reduce the lost demands as much as possible, even if it increases their costs. Therefore, the proposal of a Pareto frontier that represents the trade-off between cost and lost demand can greatly help decision-makers make decisions. In the following, some scenarios based on changes in the coefficients of objective function are presented in order to achieve an optimal solution boundary (optimal solutions set).

5. Sensitivity analysis

In this section, the performance of the proposed model is measured using scenarios based on variations in the objective functions. The results are reported in Table 12 and the behavior of the first and second objectives is depicted in Figures 4 and 5, respectively. In addition, the Pareto frontier obtained from these scenarios is illustrated in Figure 6.

Table (14): Values of objective functions obtained from the sensitivity analysis of the coefficients of the objective functions

Scenario	w_1	w_2	Z_1	Z_2
SC1	0.1	0.9	3,892,516,433	562
SC2	0.2	0.8	3,233,878,654	1,003
SC3	0.3	0.7	3,144,452,518	1,417
SC4	0.4	0.6	2,594,372,172	1,723
SC5	0.5	0.5	2,264,652,016	2,308
SC6	0.6	0.4	2,065,461,653	2,869
SC7	0.7	0.3	1,983,211,065	3,276
SC8	0.8	0.2	1,904,352,333	5,011
SC9	0.9	0.1	1,724,349,185	6,365

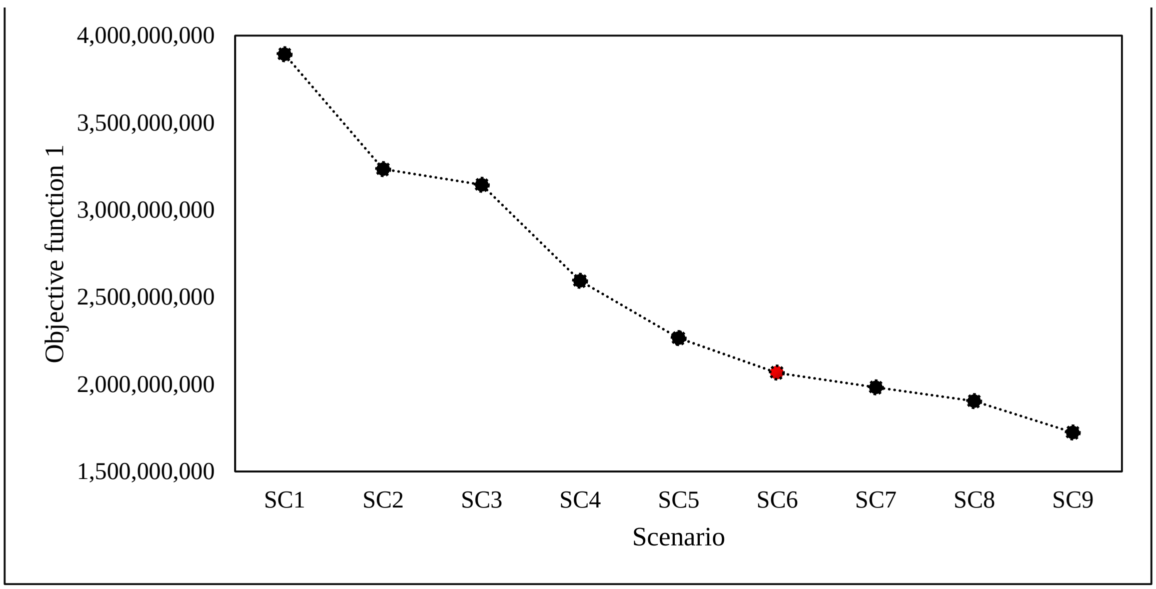

Fig. 4. Trend of variations in the first objective function obtained from the sensitivity analysis of coefficients of the objective functions

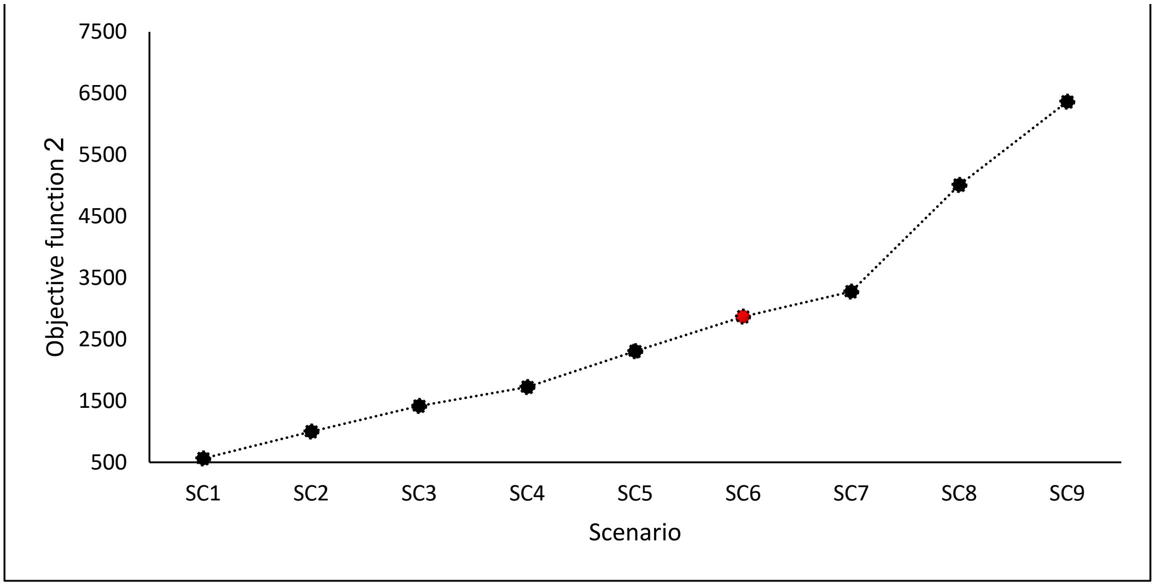

Fig.5. Trend of variations in the second objective function obtained from the sensitivity analysis of coefficients of the objective functions

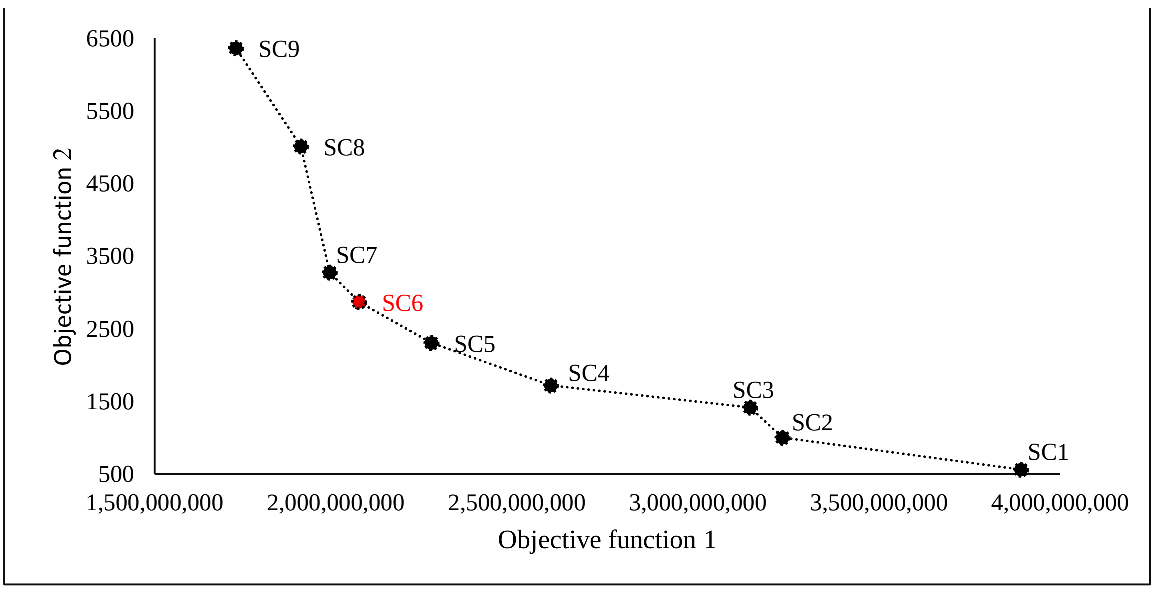

Fig. 6. Pareto frontier obtained from sensitivity analysis of coefficients of objective functions

As it can be observed in Table 14, the results obtained from the implementation of scenarios confirm the logical behavior of the proposed model and is in line with the expectations. As shown in Figure 4, the value of the first objective function has been reduced with the increase of the coefficient of the first objective function while this value has increased with the decrease of this coefficient. Similarly, the same events have occurred in Figure 5, which is related to the variation trend of the second objective function. Therefore, the performance of the proposed model is confirmed. Pareto frontier shown in Figure 6 also provides decision-makers with this possibility to choose the best scenario based on their constraints and conditions.

6. Conclusion

In this paper, a green reverse SCN was developed for the management of bread production and distribution. For this purpose, a bi-objective MILP model was proposed with the objectives of minimizing the total cost of chains and lost demands under uncertainty conditions. The location of centers, storage, being faced with shortage, i.e. lost sale, capacitated and multi-depot vehicle routing problem with simultaneous pickup and delivery, perishability, and soft and hard time windows are among the assumptions of the proposed model, which have not been simultaneously considered in any research so far according to the authors' knowledge. In this paper, an efficient multi-objective solution approach has been used to solve a bi-objective model under uncertainty conditions; and the effectiveness and efficiency of the proposed model and solution approach have been assessed using the data of a bread production and distribution chain. In addition, the performance of the proposed model was examined using the process of sensitivity analysis of coefficients of objective functions.

This study, like all pieces of research, suffers from limitations; therefore, concentration on these limitations can pave the way for future research. This paper is placed within the domain of NP-hard problems and there is not the possibility of solving the problem in large scale by GAMS software. Therefore, it is suggested that future research embark on solving the proposed large-scale problem using a heuristic or meta-heuristic algorithm.

x

Indices

r	Raw material
k	Product
f	Potential supplier
b	Potential production and separation center
m, n	Retailer
i	Potential bread drying center
j	Potential disposal center
l	Potential livestock feed market
p, q	Vehicle
c	Capacity level
t	Time period

Parameters

$F\alpha_{ft}$	The cost of ordering to supplier f in time period t
$F\beta_{b}$	The cost of setting up production and separation center b
$V\beta_{kbc}$	The cost of installing machine with capacity level c for producing product k in production center b
$F\mu_{i}$	The cost of setting up bread drying center i
$F\theta_{j}$	The cost of setting up disposal center j
$F\varphi_{p}$	The cost of purchasing vehicle p
$P\alpha_{rft}$	The cost of purchasing each unit of raw material r from supplier f in time period t
$P\beta_{kbt}$	The cost of producing each unit of product k in product center b in time period t
$P\beta'_{kbt}$	The cost of separating each unit of product k in separation center b in time period t
$P\delta^{+}_{kmt}$	The cost of holding each unit of product k in warehouse of retailer m in time period t

$P\delta^{-}_{kmt}$ The cost of lost demands for each unit of product k at location of retailer m in time period t

$P\mu_{kit}$ The cost of drying each unit of product k in bread drying center i in time period t

$P\theta_{kjt}$ The cost of disposing each unit of product k in disposal center j in time period t

$P\xi_{lt}$ The price of selling each kilogram (kg) of dried product in time period t

$C\alpha_{rft}$ The capacity of supplier f for supplying raw material r in time period t

$C\beta^{+}_{kbc}$ The maximum capacity level c for producing product k in production center b

$C\beta^{-}_{kbc}$ The minimum capacity level c for producing product k in production center b

$C\delta_{kmt}$ The demand of retailer m for product k in time period t

$C\beta_{bt}$ The capacity of separation center b for collecting the products in time period t

$C\mu_{it}$ The capacity of bread drying center i in time period t

$C\theta_{jt}$ The capacity of disposal center j in time period t

$C\varphi_{p}$ The capacity of vehicle p (m^3)

$C\xi_{lt}$ The maximum capacity of livestock feed market l for selling products in time period t

KG_{k} The weight of each unit of processed product k (kg)

VL_{k} The volume of each unit of product k (m^3)

ϖ_{rk} The amount of raw material r required for the production of each unit of product k

$\alpha\beta_{rfbt}$ The transportation cost of each unit of raw material r from supplier f to production center b in time period t

$\beta\mu_{kbit}$ The transportation cost of each unit product k from separation center b to bread drying center i in time period t

$\beta\theta_{kbjt}$ The transportation cost of each unit product k from separation center b to disposal center j in time period t

$\mu\xi_{ilt}$ The transportation cost of each kilogram of processed products from bread drying center i to livestock feed market l in time period t

$\beta\delta_{bm}$ The geographical distance of production center b from retailer m

δ_{mn} The geographical distance of retailer m from retailer n

$T\delta_{pmn}$ The time distance between retailer m and retailer n by vehicle p

$T\beta\delta_{pbm}$ The time distance between production center b and retailer m by vehicle p

TS_{pm} The service time for retailer m by vehicle p

$R\delta_{kmt}$ Return rate of product k from retailer m in time period t

PR_{kbt} Percentage of reusable product k, which is sent from separation center b to reuse centers in time period t

$(TW^{-}_{mt}, TW^{+}_{mt})$ Allowed range of time window for delivery of products to retailer m without imposing any penalty in time period t

TWF	Maximum time window allowed for the return of vehicles to production centers
LT_k	Lifetime of product k
$E\varphi$	Amount of environmental destruction arising from fuel consumption by vehicles
PE	The destruction cost of each environmental unit
PP	Penalty for each unit of time window exceeding
φ_p	The amount of fuel consumption by vehicle p per kilometer traveled
$P\varphi$	Fuel price in liters
BM	A big number

Variables

$Y\alpha_{rft}\begin{cases}1 & \text{If supplier } f \text{ is selected for purchasing raw material } r \text{ in time period } t\\ 0 & \text{Otherwise}\end{cases}$

$Y\beta_{b}\begin{cases}1 & \text{If production center } b \text{ is set up}\\ 0 & \text{Otherwise}\end{cases}$

$Y'\beta_{kbc}\begin{cases}1 & \text{If machine with capacity level } c \text{ is installed in production center } b \text{ for producing product } k\\ 0 & \text{Otherwise}\end{cases}$

$Y\mu_{i}\begin{cases}1 & \text{If bread drying center } i \text{ is set up}\\ 0 & \text{Otherwise}\end{cases}$

$Y\theta_{j}\begin{cases}1 & \text{If disposal center } j \text{ is set up}\\ 0 & \text{Otherwise}\end{cases}$

$Y\varphi_{p}\begin{cases}1 & \text{if vehicle } p \text{ is purchased}\\ 0 & \text{Otherwise}\end{cases}$

$Y_{pmnt}\begin{cases}1 & \text{If vehicle } p \text{ goes to retailer } n \text{ after serving retailer } m \text{ in time period } t\\ 0 & \text{Otherwise}\end{cases}$

$X_{pb}\begin{cases}1 & \text{If vehicle } p \text{ is allocated to production center } b\\ 0 & \text{Otherwise}\end{cases}$

$Z_{pqmt}\begin{cases}1 & \text{If vehicle } p \text{ arrives to the location of retailer } m \text{ before vehicle } q \text{ in time period } t\\ 0 & \text{Otherwise}\end{cases}$

$X\alpha\beta_{rfbt}$	The amount of raw material r purchased from supplier f by production center b in time period t
$X\beta\delta_{kpbmt}$	The amount of product k delivered to retailer m from production center b by vehicle p in time period t
$X\delta\beta_{kpmbt}$	The amount of returned product k from retailer m to separation center b by vehicle p in time period t
$X\beta\mu_{kbit}$	The amount of product k shipped from separation center b to bread drying center i in time period t
$X\beta\theta_{kbjt}$	The amount of product k shipped from separation center b to disposal center j in time period t
$X\mu\xi_{ilt}$	The amount of processed products shipped from bread drying center i to livestock feed market l in time period t

DLV_{kpmt} The deliverable amount of product k available in vehicle p after leaving retailer m in time period t

PCK_{kpmt} The amount of returned product k existing in vehicle p before entering retailer m in time period t

λT_{pmt} Entry time of vehicle p to the location of retailer m in time period t

λP_{pmt} The amount of exceeding the time window by vehicle p while visiting retailer m in time period t

η_{kmt} The inventory level in the warehouse of retailer m for product k in time period t

η^{+}_{kmt} Amount of product k available in the warehouse of retailer m in time period t

η^{-}_{kmt} The amount of lost demand for product k by retailer m in time period t

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