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ORIGINAL PAPER

Modeling the supply chain network in the fast-moving consumer goods industry during COVID-19 pandemic

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Abstract

The outbreak of the COVID-19 pandemic in recent years has raised serious concerns about the distribution of fast-moving consumer goods products, given the freshness of their use. On the one hand, the distribution of fast-moving consumer goods with multiple vehicles has led to maintaining the freshness of items at the supply chain level, and on the other hand, it involves the high costs of using vehicles. Congestion of vehicles and drivers in the distribution of items has also increased the possibility of COVID-19 transmission. The importance of the above issue has led to the modeling of a multi-level supply chain problem in the FMCG industry by considering the freshness of items to reduce COVID-19 transmission. The most important issue considered in this article is to send fresh food in the shortest possible time to customers who cannot go to stores and wait in line to buy items in the conditions of Covid-19. Therefore, the designed model provides the possibility for customers to receive fresh food in addition to reducing costs and also reduce the possibility of contracting Covid-19. Designed supply chain network levels include suppliers of raw materials, manufacturers of consumer goods, distributors and end customers. In order to optimize the objectives of the problem, including minimizing the total costs of supply chain network design and maximizing the freshness of items, various strategic and tactical decisions such as locating potential facilities, routing vehicles, and optimally allocating the flow of goods should be made. Since the supply chain network model is considered to be NP-hard, meta-heuristic algorithms have been used to solve the problem by providing a modified priority-based encoding. The results show the high efficiency of the proposed solution method in a short time.

Keywords Fast-moving consumer goods · Product freshness · Shelf life · COVID-19 pandemic · Supply chain network design · Meta-heuristics algorithm · Location-routing problem

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1 Introduction

A supply chain (SC) is usually considered as an integrated process of a group of organizations, such as suppliers, manufacturers, distributors and retailers, working together to cover and support raw materials to final products and their distribution to end customers (Szmelter-Jarosz et al. 2021). The design of the SC network is known as one of the key decision-making issues in SC management, which plays a very important role in the performance of the SC. There are various aspects in the design of a SC network, in which we can mention the location of facilities, determination of production capacity, determination of the optimal level of purchase of raw materials, the optimal amount of economic order, vehicle routing, etc. In this type of network, the actors of the SC change depending on the type of product being studied. When the question of perishability in the product is raised, inventory management, optimal production quantity and how to transfer the products are important in order to prevent damage (Ghahremani-Nahr et al. 2022). Some goods and consumables in the market have a higher sales speed than other goods and products. These products, which are found in stores and pharmacies, are usually lower priced and available in large quantities. These goods are called fast moving consumer goods (FMCG) for short. Foods, detergents and some common medicines are examples of fast moving items. Companies that produce consumer goods are identified through their ability to supply the products needed by consumers, as well as creating a sense of trust and loyalty in customers (Sisodiya and Sharma 2018). Household products make up a large part of the consumer goods industry. Ordinary medicines, health and care products, food and household cleaning products are among the fast-growing consumer goods. However, plastic goods, stationery and most medicines can also be included in this category. From the consumer's point of view, fast consumer goods are relatively cheap and part of the daily requirement. For this reason, these products should always be available in stores and markets close to residential areas (Sekerin et al. 2018). Of course, large companies that produce these goods do not sell their products directly to end consumers, but use an extensive network of retailers to do so. In order for consumer goods to reach consumers from manufacturers to distributors, from distributors to retailers, and from retailers to customers (Pandukuri et al. 2017). One of the characteristics of this industry is the high sales volume and the use of an extensive network of retailers. Therefore, distribution operations in it are vital and very costly. Procurement managers are always under pressure to reduce costs in this sector. Accordingly, in recent years and with the outbreak of COVID-19 pandemic, the distribution of consumer goods, especially food, has accelerated and the amount of production, distribution and supply of related raw materials has increased (Singh et al. 2020). The management and transportation of these goods is very difficult and the costs associated with transportation, distribution and maintenance have increased dramatically (Shetty et al. 2020).

The high perishability of perishable goods such as food and medicine and the high cost of maintaining them in order to maintain the freshness of the products have led to the complexity of this type of SC networks. Preserving the freshness of products requires more use of vehicles to transport products quickly. Products with high perishability cannot be kept in warehouses for a long time. Because these types of products must be quickly transferred to the demand points (customers) and their freshness must be maintained. As mentioned, the storage of perishable goods in the warehouses of distribution centers has a high cost in order to improve the level of storage technology and refrigerators suitable for the products. Therefore, the accurate determination of the order amount from the demand points and sending it to the production centers can greatly reduce the costs of storing fast consuming products. On the other hand, it is important to distribute fast-moving products with multiple vehicles that can maintain the freshness of the products. Therefore, proper management should be done on the SC method of fast consumer goods in order to reduce the costs of the total SC network and consider the freshness of the products. SC management includes the management of all activities and processes related to the supply, production and distribution of products by the supplier to end customers during the planning horizon. Various decisions are made in the management of SC networks, including strategic and tactical decisions (Ghahremani-Nahr et al. 2019a). As strategic decisions are long-term decisions, they will have a significant impact on the management of FMCG industry SC network costs. While tactical decisions occur after strategic decisions and usually, include a planning horizon of 1–5 years. In such decisions, various items such as the amount of raw material supply, the amount of production and storage of products, the amount of distribution and how to transport fast-moving products and finally the routing of vehicles are adopted (Ghahremani-Nahr et al. 2019a). As a result, in a SC network, both strategic and tactical decisions must be made simultaneously. In making decisions related to the SC network, the type of products under consideration is of great importance. In addition to managing the costs associated with network design decisions, managing the freshness of products delivered to customers is also important in the COVID-19 pandemic. Therefore, in order to provide a comprehensive model of SC, to reduce the cost of location-allocation and routing of the vehicle and maximize the freshness of fast food products in the food sector. The importance of this issue is that in order to prevent the decline of food freshness, multiple vehicles with more numbers should be used for distribution. This increases the cost of using vehicles and transporting products, as well as congestion of vehicles and drivers in the city. Therefore, with the increase in the number of vehicles, in addition to increasing costs, the possibility of transmitting the COVID-19 virus also increases. However, another goal of SC network design is to reduce the costs associated with it. Therefore, two conflicting goals are considered in this article. The model intended for the SC of the fast food industry in the food sector includes raw material suppliers, product manufacturers, distributors and end customers. Since the possibility of direct distribution leads to increased costs as well as the possibility of transmitting the COVID-19 virus, vehicle routing has been used to distribute products from distribution centers to customers. It has become difficult to consider different location-allocation and routing decisions, leading to complexity and NP-hardness. In this research, in addition to providing a mathematical model to simultaneously optimize costs and maintain the quality of freshness products in the consumer goods industry, to solve the model using MOGWO, MOALO and NSGA II by presenting a modified chromosome. In order to achieve the two objective functions simultaneously, strategic decisions such as locating production and distribution centers and tactical decisions such as optimal allocation of flow through vehicles between different levels and vehicle navigation in distributing products between distribution centers and customers must be made.

The structure of the article is as follows: In the second part, a review of the research literature and review of articles in the field of SC for the food sector in the FMCG industry is provided. In the third part, a two-objective mathematical model for designing a SC network in the FMCG industry for the food sector is presented. The fourth section refers to the theoretical foundations of meta-heuristic algorithms (MHA)s, modified chromosome design based on modified priority, and a comparison index of MHAs. In the fifth section, problem analysis, numerical example solving and sensitivity analysis are discussed. Finally, in the sixth section, the conclusions and future suggestions of the research are presented.

2 Literature review

Sharma and Sengar (2012) optimized service levels to increase the freshness and availability of products to end consumers in a multi-level system for the FMCG industry. They developed a new approach to increasing the level of service of distribution centers and the inventory of the total value chain. Van Elzakker et al. (2014) presented a tactical plan for the industry to reduce the rapid consumption industry using a mixed integer model. They proposed both direct and indirect methods and concluded that the indirect method leads to the depletion of inventory in the warehouse before the period of their corruption. Amorim and Almada-Lobo (2014) modeled a multi-objective model to minimize routing costs and maximize product freshness. They used the Epsilon constraint method to solve the problem. They also used a multi-objective evolutionary algorithm to solve large size problems. Une and Sangle (2014) increased profitability through efficient SC management for the consumer goods industry. Through a survey in Maharashtra in the arts, they examined the impact of SC performance parameters on the profitability of the FMCG sector and showed that proper SC management leads to positive results in corporate profitability. In a study, Davis et al. (2014) considered the collection and delivery of food to an organization that helps hunger. They proposed the use of food delivery points (FDPs) to increase access to food and proposed a capacitive set cover model for identifying FDP sites. Morganti and Gonzalez-Feliu (2015) examined urban procurement for perishable products through a case study of the Parma food hub in Italy. In this article, they analyze plans to deliver food to urban distributors, such as corporate retail chains, independent retailers, and hotels, restaurants, and kit stores. Berghenti et al. (2015) examined RFID in the FMCG SC for product freshness. They observed that based on the data collected, RFID could have a significant impact on sales, reduced capital costs, and product freshness for end customers. Manders et al. (2016) presented an integrated approach to the SC flexibility of consumer goods, including suppliers, manufacturers, logistics providers, and retailers. Findings show that each member of the chain uses flexibility to meet the direct needs of the next row chain members. González-Torre and Coque (2016) analyzed the impact of banks' food on the SCs to which they belong. They first summarized the background of international research on the subject and then presented the results of an empirical study in Spain. Data were collected through surveys and analyzed using the cluster method. Elsaleiby (2019) presented a mixed integer linear programming model for optimizing the consumer goods SC network. Random data in different sizes of SC network were used to evaluate the model. The results showed the high performance of the model designed for the FMCG industry. Martins et al. (2019) proposed a mixed integer linear model for the problem of redesigning a multi-stage SC network for the collection and distribution of food aid to charities, which addresses all dimensions of sustainability, economic, environmental and social There are three objective functions. Their studies show that the greatest alignment occurs between economic goals and the other two goals, and that attributing the highest priority to environmental goals leads to the most balanced solutions.

Wetherill et al. (2019) conducted a study to describe the best practices and strategies for advancing food-focused nutrition banking in the United States. They used qualitative interviews to obtain information about food banking practices and processes from a targeted sample of food bank executives (30 people) and examined them using code-based qualitative content analysis. Martins (2019) in a study redesigned the SC from a multidimensional perspective on sustainability in which the SC is formulated as a three-tier network including donors, food banks and charities. He formulated the problem as a dynamic and capacitive model using a three-objective mixed integer linear programming method. Ataseven et al. (2020) used managerial survey data and secondary data collected from the Feeding America website to model and measure foodbank performance to examine the relationship between supply integration, demand integration, and internal integration in food banking. They tested the hypothesis using regression and Monte Carlo simulation techniques. Findings show that for food for non-profit banks, external mergers should be done before internal mergers and demand mergers have a stronger effect on performance than supply mergers. Mahajan (2020) examined the impact of the COVID-19 pandemic on FMCG in India, as well as its impact on consumer behavior and employment. He concluded that protection, hygiene and disinfection methods could help prevent the spread of COVID-19 in the FMCG industry. Okunade and Daodu (2020) designed a fast-moving consumer goods distribution network with the aim of maximizing customer satisfaction and minimizing distribution costs. They defined and solved a real case study in southwestern Nigeria as a linear planning model to reduce the total cost of distribution from power plant to warehouses by considering four routing options. The results show that distribution through intermediaries offers a better solution than the direct shipping routing option.

The impact of leather whipping on the SC of FMCG enterprises with several products and levels was examined by Ali et al. (2020). Using a discrete-event simulation technique, they looked at how this element affected the situation. The findings indicate that while the effect of the leather whip cannot be completely eradicated, it may be diminished with careful information exchange. Based on large data from the Internet of Things, Nozari and Ghahremani-Nahr (2021) identified the factors impacting SC agility and proposed the conceptual framework of agile SC in high-consumption businesses. The study's findings led to the development of a framework that aims to meet the organization's demands for agility in an informed way. Končar et al. (2020) examined the obstacles to business process digitization and the stability of SCs based on the Internet of Things in the FMCG sector. During the COVID-19 epidemic, they performed the research with a range of SC members from production, distribution, wholesale, and retail. The competent institutions and SC management FMCG were advised to employ a set of measures and incentives to support the digitalization process based on the findings. Nozari et al (2021) study of the SC in the FMCG sector offered a thorough analytical framework for creating a long-lasting, intelligent SC based on IoT-based big data analytics. The suggested framework is built on the IoT implementation technique, with a focus on using big input data and targeted surveys. They demonstrated how this may result in wiser production choices given the characteristics of the FMCG sector.

For the creation of an economic production quantity (EPQ) model that incorporates warehouse space and financial restrictions while excluding scarcity, Askari et al. (2020) suggested a mixed-integer nonlinear programming model. Two MHAs are used to solve the problem, and different examples in a range of dimensions are generated to show how successful the methods are. According to Madhavi and Wickramarachchi (2021), it is crucial to assess how the COVID-19 pandemic would affect the FMCG sector and how SC resilience will perform better in times of crisis. Nozari et al (2021) presentation of the study issue offers potential solutions for IoT-based SC management in FMCG Industries. The outcomes showed that among the collected security requirements for IoT-based SC management, dependability and privacy, together with their sub-criteria, were the most crucial. In a sustainable agriculture product SC network (SAPSCN), Goodarzian et al. (2021a) created a mixed-integer linear programming (MILP) framework for the production–distribution-routing issue. In order to verify the mathematical model, they offered a real-world case study. The hybrid simulated annealing (SA) and particle swarm optimization (PSO) findings highlight the fact that it is more reliable than other proposed techniques to solve the issue in a suitable amount of time. In an integrated economic production quantity (EPQ) model with partial backorders and re-workable items taking into account linear and fixed backordering costs, Gharaei et al. (2021) established the lot-sizing strategy. For the integrated EPQ model's optimal lot-sizing, they adopted an outer approximation (OA).

In the sustainable medical SC network, Goodarzian et al. (2021b) created a production–distribution–inventory–allocation–location issue. Additionally, the distribution of medications for COVID-19 patients and the timing of medication manufacturing and delivery in light of some medications' perishability are taken into account. The work uses a genuine case study, and the empirical findings show that the hybrid fish swarm (FSA) with variable neighbourhood search is preferable. In order to find the best prices for products in various sales and distribution channels for FMCG companies while integrating location-allocation choices and inventory control of distribution centres in an uncertain environment, Nasiri et al. (2021) developed a mixed-integer non-linear programming model. A bi-objective closed-loop SC was created by Pouralikhani et al. (2021) using a Robust Possibilistic Programming (RPP) method. The goal of this article is to reduce the price and amount of time it takes to deliver the goods to the consumer. To support the model's validity, the model's output and the results of the sensitivity analysis are provided. Taleizadeh et al. (2022) investigated the best choices and operational tactics for a logistics network that took into account two capital-constrained producers that make goods of various quality and sell them to a retailer with deterministic demand over a predetermined time period. For a new sustainable-resilient health care network associated to the COVID-19 pandemic under uncertainty, Goodarzian et al. (2022) designed a production, allocation, location, inventory keeping, distribution, and flow problems that also incorporated sustainability and resiliency ideas. They utilised three MHAs, such as the multi-objective teaching and learning approach. The viability of employing null-space-based factorisations to develop sparse direct techniques was examined by Gharaei et al. (2022). Finding the ideal quantity of stockpiles and the length of the economic holding period for inventories are the paper's main goals. By performing a literature analysis and speaking with professionals working in the FMCG sector as a case study, Nozari et al. (2022) were able to identify the key issues facing the AIoT-powered SC. The findings indicated that the two biggest problems the AIoT-based SC is now experiencing are insecurity and a lack of adequate infrastructure.

By reviewing the literature and comparing the articles with each other, it can be stated that different models have been designed for food distribution such as SC, vehicle routing, hub location, etc. While reviewing the articles, it can be seen that there is no mathematical model in the SC for the FMCG industry and the food sector that simultaneously, in addition to reducing network design costs, recently deals with COVID-19 pandemic products.

Therefore, in this article, the main features of the model can be summarized as follows:

- Design of a new model of SC network in the FMCG industry during the COVID-19 pandemic.
- Consider the freshness of the distribution of consumer goods along with cost reduction.
- Provide a modified priority chromosome based on problem solving with MHAs.

Based on the research gap created, a SC network problem for the FMCG industry under the COVID-19 pandemic conditions is further modeled.

3 Problem definition and modeling

In this part of the paper, a SC network design model for the FMCG industry under the COVID-19 pandemic is presented. The SC network model is intended for the food sector, the main purpose of which, according to Fig. 1, is to locate distribution and production centers, to optimally allocate the flow of products between different levels of the SC network, and to route vehicles. In the distribution of

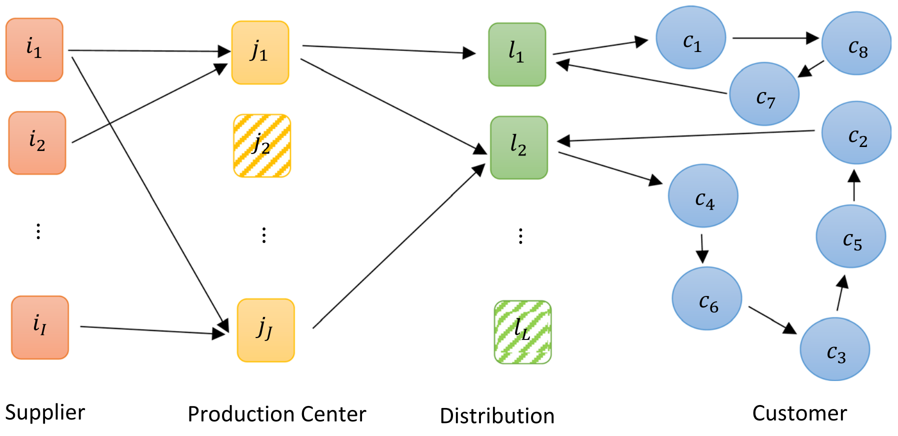

Fig. 1 SC network for FMCG industry

food to customers. According to Fig. 1, the intended SC network includes levels such as raw material suppliers, production centers, distribution centers and end customers. In this network, raw material suppliers send the necessary materials to produce production centers. Production centers after the production of fast food products, they send them to distribution centers for distribution. In this section, first, potential production and distribution centers must be identified in advance, and in case of construction, their production and distribution capacity can be used to establish a network. Finally, distribution centers distribute products with multiple vehicles according to the demand of each customer. In this part of the SC network, product freshness is considered and the goal is to distribute products quickly.

Consumer fast products lose their quality and freshness over time. As a result, one of the goals of the model is to maximize the level of freshness of products distributed to customers. To do this, multiple vehicles are required, which increases the logistics and design costs of the SC network. On the other hand, with the increase in the number of vehicles for the distribution of products, the congestion of vehicles in the city has increased, which increases the possibility of COVID-19 virus. Therefore, the most appropriate type of network design should be determined based on reducing the cost of designing the total SC network (potential location, optimal flow allocation and vehicle routing) and increasing the level of freshness of products distributed to customers. It should also be noted that the level of freshness of products decreases with the passage of time, and customers are interested in receiving high-quality fast food products.

Based on the main objectives, including minimizing SC network design costs and maximizing product freshness, the assumptions of the SC network model for the FMCG industry are as follows:

- The model is considered as a single-period and multi-product.
- Shortages are not allowed and all customer demands must be answered.

- The level of freshness of products is considered only in the distribution of consumer goods.
- The level of freshness of products is inversely related to the passage of time and with increasing time, the level of freshness of products decreases exponentially.
- The capacity of the centers is known in advance.
- The location of the facility includes unknown production and distribution centers.
- Each customer's demand is estimated by only one distribution center.
- Distribution of products to customers from distribution centers is a vehicle routing model
- Increasing the number of vehicles to distribute products increases the likelihood of transmitting the COVID-19 virus.

According to the above assumptions, the nonlinear model of the SC network problem for the FMCG industry in the food sector under the COVID-19 pandemic conditions is modeled as follows.

3.1 Sets

I Set of raw material suppliers

J Set of production centers

L Set of distribution centers

C Set of customers

N Total set of $n \in L \cup C$ customer nodes and distribution centers

V Set of vehicles

P Set of food material

3.2 Parameters

f_l The cost of choosing a distribution center $l \in L$

h_j The cost of choosing a production center $j \in J$

g_v The cost of using the vehicle $v \in V$

$o_{l,p}$ Operating cost for food $p \in P$ distribution at distribution center $l \in L$

$\xi_{n,n'}$ Shipping cost from node $n \in N$ to node $n' \in N$

$\xi'_{i,j}$ Shipping cost from supplier $i \in I$ to production center $j \in J$

$\xi''_{j,l}$ Shipping cost from production center $j \in J$ to distribution center $l \in L$

$d_{c,p}$ Demand of customer $c \in C$ of food $p \in P$

$\psi_{l,p}$ The maximum capacity of the distribution center $l \in L$ of the food $p \in P$

$\varpi_{j,p}$ Maximum capacity of the production center $j \in J$ of food $p \in P$

γ_v Maximum capacity of vehicle $v \in V$ for food distribution

$k_{n,n'}$ Shipping time from node $n \in N$ to node $n' \in N$

φ_c Service time for customer $c \in C$

u_p Shelf life of food $p \in P$

$BigM$ Positive big number

3.3 Decision variables

$W_{l,p,v}$ Number of food $p \in P$ distributed by distribution center $l \in L$ by vehicle $v \in V$

$D_{l,c,v}$ Time of arrival of the vehicle $v \in V$ to the customer $c \in C$ who has left the distribution center $l \in L$

$F_{l,c,v,p}$ Freshness of food $p \in P$ distributed by distribution center $l \in L$ on arrival at customer $c \in C$ by vehicle $v \in V$

$Y_{j,l,p,v}$ Number of food $p \in P$ transferred from production center $j \in J$ to distribution center $l \in L$ by vehicle $v \in V$

$O_{i,j,p,v}$ Number of food $p \in P$ transferred from supplier $i \in I$ to production center $j \in J$ by vehicle $v \in V$

$U_{c,v}$ Auxiliary variable to remove sub-tour

$X_{n,n',v}$ The value is 1, if the vehicle $v \in V$ moves from node $n \in N$ to node $n' \in N$; Otherwise it takes the value 0

$R_{l,c,v}$ The value is 1, if the vehicle $v \in V$ removed from the distribution center $l \in L$ to visit customer $c \in C$; Otherwise it takes the value 0

Z_l The value is 1, if the distribution center $l \in L$ is selected for food distribution; Otherwise it takes the value 0

Z'_j The value is 1, if the production center $j \in J$ is selected for food production; Otherwise it takes the value 0

$A_{i,j,v}$ The value is 1, if vehicle $v \in V$ is used to transport food between the supplier $i \in I$ and the production center $j \in J$; Otherwise it takes the value 0

$B_{j,l,v}$ The value is 1, if vehicle $v \in V$ is used to transport food between the production center $j \in J$ and the distribution center $l \in L$; Otherwise it takes the value 0

C_v The value is 1, if vehicle $v \in V$ is used to distribute food in the routing section; Otherwise it takes the value 0

3.4 FMCG industry SC network design

The nonlinear mathematical model of the food distribution network in the three-tier SC network is as follows:

$$\min \sum_{l\in L} f_l \cdot Z_l + \sum_{j\in J} h_j.Z'_j + \sum_{v\in V} g_v \cdot C_v + \sum_{i\in I}\sum_{j\in J}\sum_{v\in V} g_v \cdot A_{i,j,v} + \sum_{j\in J}\sum_{l\in L}\sum_{v\in V} g_v \cdot B_{j,l,v} + \sum_{l\in L}\sum_{p\in P}\sum_{v\in V} o_{l,p} \cdot W_{l,p,v} + \sum_{n\in N}\sum_{n'\in N}\sum_{v\in V} \xi_{n,n'} \cdot X_{n,n',v} + \sum_{j\in J}\sum_{l\in L}\sum_{p\in P}\sum_{v\in V} \xi'_{j,l} \cdot Y_{j,l,p,v} + \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{v\in V} \xi''_{i,j} \cdot O_{i,j,p,v} \tag{1}$$

$$max \sum_{l\in L}\sum_{c\in C}\sum_{p\in P}\sum_{v\in V} Fr_{l,c,v,p} \tag{2}$$

s.t.:

$$\sum_{v\in V}\sum_{n\in N} X_{n,c,v} = 1, \quad \forall c \in C \tag{3}$$

$$\sum_{n'\in N} X_{n',n,v} = \sum_{n'\in N} X_{n,n',v}, \quad \forall v \in V,\ n \in N \tag{4}$$

$$\sum_{l\in L}\sum_{c\in C} X_{l,c,v} \le 1, \quad \forall v \in V \tag{5}$$

$$\sum_{v\in V} R_{l,c,v} \le 1, \quad \forall l \in L,\ c \in C \tag{6}$$

$$-R_{l,c,v} + \sum_{n\in N}\left(X_{l,n,v} + X_{n,c,v}\right) \le 1, \quad \forall l \in L,\ c \in C,\ v \in V \tag{7}$$

$$U_{c,v} - U_{c',v} + |C|X_{c,c',v} \le |C| - 1, \quad \forall c \in C,\ c' \in C,\ v \in V \tag{8}$$

$$W_{l,p,v} \ge \sum_{c\in C} d_{c,p}.R_{l,c,v}, \quad \forall l \in L,\ p \in P,\ v \in V \tag{9}$$

$$\sum_{j\in J}\sum_{v\in V} Y_{j,l,p,v} = \sum_{v\in V} W_{l,p,v}, \quad \forall l \in L,\ p \in P \tag{10}$$

$$\sum_{i\in J}\sum_{v\in V} O_{i,j,p,v} = \sum_{l\in L}\sum_{v\in V} Y_{j,l,p,v}, \quad \forall j \in J,\ p \in P \tag{11}$$

$$\sum_{l\in L}\sum_{v\in V} Y_{j,l,p,v} \le \varpi_{j,p} \cdot Z'_j, \quad \forall j \in J,\ p \in P \tag{12}$$

$$\sum_{v\in V} W_{l,p,v} \le \psi_{l,p} \cdot Z_l, \quad \forall l \in L,\ p \in P \tag{13}$$

$$\sum_{p\in P} O_{i,j,p,v} \le \gamma_v \cdot A_{i,j,v}, \quad \forall i \in I,\ j \in J,\ v \in V \tag{14}$$

$$\sum_{p\in P} Y_{j,l,p,v} \le \gamma_v \cdot B_{j,l,v}, \quad \forall j \in J,\ l \in L,\ v \in V \tag{15}$$

$$\sum_{c\in C}\sum_{n\in N}\sum_{p\in P} d_{c,p} \cdot X_{n,c,v} \le \gamma_v \cdot C_v, \quad \forall v \in V \tag{16}$$

$$D_{l,c,v} \ge k_{l,c} - BigM \cdot \left(1 - X_{l,c,v}\right), \quad \forall l \in L,\ c \in C,\ v \in V \tag{17}$$

$$D_{l,c',v} \ge D_{l,c,v} + k_{c,c'} + \varphi_c - BigM \cdot \left(2 - X_{c,c',v} - R_{l,c,v}\right), \quad \forall l \in L,\ c \in C,\ c' \in C,\ v \in V \tag{18}$$

$$F_{l,c,v,p} \geq 100e^{-\frac{D_{l,c,v}}{u_p}} - BigM \cdot \left(1 - R_{l,c,v}\right), \quad \forall l \in L,\ c \in C,\ p \in P,\ v \in V \tag{19}$$

$$D_{l,c,v} \leq BigM \cdot R_{l,c,v}, \quad \forall l \in L,\ c \in C,\ v \in V \tag{20}$$

$$X_{l,l',v} \leq 0, \quad \forall l \in L,\ l' \in L,\ v \in V \tag{21}$$

$$D_{l,c,v}, F_{l,c,v,p}, U_{c,v}, W_{l,p,v}, Y_{j,l,p,v}, O_{i,j,p,v} \geq 0 \tag{22}$$

$$R_{l,c,v}, X_{n,n',v}, Z_j', Z_l, A_{i,j,v}, B_{j,l,v}, C_v \in \{0, 1\} \tag{23}$$

Equation (1) Minimizes the total costs of SC network design, including the costs of selecting and constructing production and distribution centers, the cost of operating vehicles, transmission and routing costs. Equation (2) seeks to maximize the freshness of food delivered to customers from all products. Equation (3) ensures that one of the total vehicles is allowed to deliver food to each customer. Equation (4) shows that each vehicle must leave a customer after it has been visited. Equations (5) and (6) ensure that a maximum of one vehicle is allowed to deliver food to customers. Equation (7) ensures that each vehicle must start from a distribution center and return to the same center after meeting customer demand. Equation (8) is related to the subtraction elimination equation. Equation (9) shows the total amount of food distributed to customers by the vehicle leaving each distribution center. Equations (10) and (11) show the number of materials transferred from production centers to distribution centers, as well as suppliers of raw materials to distribution centers, respectively. Equations (12) and (13) show, respectively, that until a production or distribution center is selected and built, the maximum capacity of that center cannot be used to produce or distribute food. Relationships (14) to (16) show the type of vehicle used to transport spicy food between different levels of the SC network. Equations (17) and (18) calculate the arrival time of the vehicle for the delivery of food to each customer. In relation (17) shows the time of arrival of the vehicle in visiting the first customer and in relation (18) shows the time of arrival of the vehicle in visiting other customers. In this regard, service time for each customer, including food delivery is also considered. Equation (19) shows the freshness of food at the time the vehicle arrives at each customer. Relationships (20) and (21) show the logical relationships between decision variables. Equations (22) and (23) show the variables zero and one and continuous.

Due to the non-linearity of the SC network model designed in this section and also making simultaneous strategic and tactical decisions such as locating potential facilities, optimal flow allocation and vehicle routing, multi-objective grey wolf optimizer (MOGWO), multi-objective ant lion optimizer (MOALO) and non-dominated sorting genetic algorithm (NSGA II) were used to solve the model. Has been. In the following, the generalities of the algorithms are described as well as the design of the primary chromosome based on the modified priority.

4 Solving methods and comparing indicators

In this section, different solution methods are presented as well as the design of the primary chromosome based on the modified priority to solve the SC problem of the FMCG industry in the COVID-19 pandemic conditions. Therefore, first, each of the algorithms and their operators are described, and then, after presenting the chromosome and decoding it, the comparison indicators of NSGA II, MOGWO and MOALO are presented.

4.1 NSGA II

The operational complexity of this algorithm is lower than that of other algorithms, making it one of the quickest and most potent optimization algorithms. Ensures that they fall within a desirable range for changing objective functions and allows the designer the opportunity to choose the optimum design of his choice. The maintenance of elitism and dispersion are taken into account concurrently in NSGA II. This approach bases the choosing of a new population in each stage on the dominance principle and, at each phase of the solution, chooses the best undefeated solutions before moving on to the next. In the case when there are two maximizing objective functions, g_1 and g_1, solution x outperforms solution y. $(x < y)$ ff $g_1(x) \geq g_1(y)$ and $g_2(x) \geq g_2(y)$, or if $g_1(x) > g_1(y)$ and $g_2(x) > g_2(y)$. In addition, the concept known as congestion distance is utilized in this method in order to ensure that the density of the solutions is distributed in the appropriate manner (Deb et al. 2000).

In order to sort a population of size n based on the levels of non-defeat, each solution in the population is frequently compared to every other solution in the population to determine whether or not it is defeated. These solutions are added to the set designated as F1. The answers that were found in the first boundary are ignored for the time being while the procedure that was just detailed is carried out once more. The only difference this time is that the solutions are relocated to the F2 set and given the position of second place. This process is repeated for each of the issues that the population is still struggling with. One of the prerequisites for the evolutionary algorithm to approach the ideal Pareto boundary is that the collection of solutions that have been identified must, at all times, preserve the diversity and breadth of the solutions that have been found. In point of fact, organizing non-defeats is a way that may be used to arrive at better answers, and the process of variety also attempts to maintain these solutions in a manner that is diverse and all-encompassing. Swarming at a distance in this manner is the means through which this objective can be attained using this strategy. As the swarming distance between two solutions reduces, the density of solutions in close proximity to each other increases. Choose the alternatives for the following phase that are further away from crowded areas and located in places with a lower population density. As a direct consequence of this, the solutions that are developed contain a greater variety and dispersion. Within NSGA II, the utilization of congestion spacing is essential for the diversification of population responses as well as the demonstration of the response density in close proximity to a specific response.

4.2 MOALO

The science of MOALO was influenced by research on how ants and ant milk interact. There are two populations in the ant milk algorithm: the ant collection and the ant milk collection (Mirjalili et al. 2017). Ants' primary duty is to scout out the search area. MOALO mimics the stochastic phase of ants, diving into an ant milk cavity, making a hole, the ant crawling towards the ant milk, collecting food, refurbishing the cavity, and making a choice in order to solve optimization problems. The following describes the primary random phase employed by MOALO to replicate the random phase of ants:

$$X(t) = \left[0, cumsum\left(2r\left(t_1\right) - 1\right), cumsum\left(2r\left(t_2\right) - 1\right), \ldots, cumsum\left(2r\left(t_n\right) - 1\right)\right] \tag{24}$$

$$r(t) = \begin{cases} 1 & if\ rand > 0.5 \\ 0 & if\ rand \leq 0.5 \end{cases} \tag{25}$$

where *cumsum* is the cumulative sum, n is the maximum number of iterations, and t is the random step phase and rand is the random number born with a uniform distribution at intervals [0, 1]. In order to maintain a random step at the boundaries of the search space and to prevent over-hunting, random steps must be normalized according to the following equation:

$$X_i^t = \frac{\left(X_i^t - a_i\right) \times \left(d_i^t - c_i^t\right)}{\left(b_i - a_i\right)} + c_i^t \tag{26}$$

where c_i^t is the minimum i-th variable in the t-th repeat, d_i^t is the maximum i-th variable in the t-th repeat, a_i is the minimum random step of the i-th variable, and b_i is the maximum random step in the i-th variable. The MOALO simulates the entrapment of ants in the ant lion cavity by changing random steps around the ant lion. The following equations are presented in this regard:

$$c_i^t = Antlion_j^t + c^t \tag{27}$$

$$d_i^t = Antlion_j^t + d^t \tag{28}$$

c^t Minimum variables in t-iteration, d^t vector containing maximum of all variables in t-th iteration, c_i^t Minimum variables for i-th, d_i^t Maximum all variables for i- th ant, $Antlion_j^t$ is the position of the j antlion selected in the t-iteration. Catching the ant and re-building the pit are the next-to-last steps in the ant lion algorithm. The process is simulated by the following equation:

$$Antlion_j^t = Ant_i^t \quad if\, f\left(Ant_i^t\right) < f\left(Antlion_j^t\right) \tag{29}$$

$Antlion_j^t$ indicates the position of the j-th ant of the selected ant in the t-th iteration, and Ant_i^t indicates the position of the i-th at the t-th repeat. The "ant lion" algorithm's last operator is elitism, which stores the best ant lion that was created throughout optimization. Only this ant lion has the power to influence all ants. This indicates that the chosen ant lion advances towards the direction of the elite ant lion. The following is how the equation treats them both:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{30}$$

Ant_i^t indicates the position of the i-th ant at the t-th repeats, R_A^t represents the random motion in the selected ant lion at the t-th repeat, and R_E^t represents the random motion around the elite at the t-th repeat.

4.3 MOGWO

Canis Iupus, sometimes known as the gray wolf, is a member of the Candidae family. Gray wolves are the top predators in both the food pyramid and the food chain. They are also at the top of the food pyramid. The vast majority of gray wolves choose to make their home in groups known as packs. The average wolf pack contains anywhere from five to twelve members. The male and female members of the leadership team are both referred to as alphas. Alpha is the primary decision-maker for a variety of issues, including hunting, sleeping arrangements, wake-up times, and other topics. Choices made by the Alpha are communicated to the group, although there have been examples of democratic behavior in which an Alpha just follows the lead of the other wolves in the pack. When there is a community, everyone in the herd rallies behind Alpha. The dominant wolf is another name for the alpha wolf. This is due to the fact that the orders given by the alpha wolf must be carried out by the entire pack. The alpha wolves are not allowed to mate outside of the herd at any time (Mirjalili et al. 2016).

It is essential to keep in mind that the Alpha is not always the member of the herd who possesses the greatest physical prowess, but rather the one who is the most skilled in terms of herd management. The rank that comes after Alpha in the social structure of gray wolves is called Beta. Beta are wolves that offer advice and assistance to Alpha when it comes to making decisions for the herd. If for whatever reason the Alpha wolf were to perish or get old, the best possible replacement would be the Beta wolf, which may be male or female depending on the circumstances. Beta is responsible for carrying out Alpha's directives throughout the herd and providing feedback to Alpha. The Omega wolf is the lowest ranking member of the gray wolf pack, according to its social structure. Wolf Omega plays the role of the hapless victim. It is common practice for the more strong and dominant wolves to demand obedience from Omega wolves. They are the only wolves left that are able to consume food. If a wolf does not fit the profile of either an Alpha or an Omega, then we call it a Delta. It is necessary for Alpha and Beta wolves to maintain control over Delta wolves. However, they are the ones who rule Omega. In the mathematical modeling of the wolf social hierarchy, alpha is considered to be the best option since it represents the best possible course of action. Therefore, Beta and Delta are the two responses that are the second and third most appropriate. The final possible response, Omega, is selected from those that remain. In order to successfully hunt, gray wolves need to identify their prey and then encircle it.

4.4 Primary chromosome design

After describing MHAs, the most important part is related to the design of the initial solution (primary chromosome). The intended SC network consists of 3 different layers. According to Fig. 1 in the first layer, the problem of vehicle routing and in the second and third layers, the problem of optimal allocation of product transfer flow along with the location of facilities is considered. Therefore, a matrix according to Fig. 2 is considered for the design of the primary chromosome (Ghahremani-Nahr et al. 2019b). To better illustrate Fig. 2, the chromosome is designed to consist of 5 customers, 3 distribution centers, 4 production centers and 3 raw material suppliers.

According to Fig. 2 the length of the designed chromosome is $(|I| + 2|J| + 2|L| + |C|)$. To design a chromosome to be decoded, the following steps must be performed for the first layer:

Step 1 The highest priority among the distribution centers is selected as the center for food distribution [for example, distribution center 3 with high priority (5) is selected].

Step 2 The highest priority among customers is the selection and basis of the capacity of the randomly assigned vehicle and the capacity of the selected distribution center, vehicle routing is performed (for example, it is assumed that due to the limitations of vehicle routing capacity has been $l_3 \rightarrow c_5 \rightarrow c_3 \rightarrow c_2 \rightarrow l_3$).

Step 3 If the demand of all customers is not met, steps 1 and 2 are repeated.

After decoding the first layer, distribution centers are selected to meet customer demand and vehicle routing is determined. Then, based on the selected distribution centers, the second layer decryption is performed based on the following steps:

Distribution Centers + Customers Level 1	l_1 2	l_2 4	l_3 5	c_1 1	c_2 6	c_3 7	c_4 3	c_5 8
Production Centers + Distribution Centers Level 2	j_1 7	j_2 5	j_3 1	j_4 2	l_1 4	l_2 6	l_3 3	
Suppliers + Production Centers Level 3	i_1 3	i_2 6	i_3 2	j_1 5	j_2 4	j_3 1	j_4 7	

Fig. 2 Initial solution of the SC network problem for the FMCG industry

Step 1 If the distribution center is not selected in the first layer, its priority in the second layer is reduced to zero (for example, the priority of the distribution center 1 is reduced to 0).

Step 2 The highest priority is selected from the second layer genes (for example, Production Center 1 with the highest priority).

(A) If the priority is related to the production center, as long as the capacity of this center can be used, the allocation of demand to the distribution centers will be done based on the lowest transportation cost.

(B) If the priority is related to the distribution center, until the demand of this center is not met, the allocation of supply from the production centers will be done based on the lowest transportation cost.

Step 3 At each stage, the capacity of the production center and the demand of the distribution center are updated.

Step 4 If the capacity of the production center or the demand of the distribution center is zero, the corresponding priority in the second layer chromosome will be reduced to zero.

Step 5 Steps 2–4 continue until the priority of all distribution centers is reduced to 0.

After optimally allocating the flow of fast consumer goods between the production center and the distribution center, the third layer of the designed chromosome is decoded according to the following steps:

Step 1 If the production center is not selected in the second layer, its priority in the third layer is reduced to zero (for example, the priority of the production center 3 and 4 is reduced to 0).

Step 2 The highest priority is selected from the third layer genes (for example, supplier 2 with the highest next priority).

(A) If the priority is related to the supplier, as long as the capacity of this center can be used, the allocation of demand to the production centers will be done based on the lowest transportation cost.
(B) If the priority is related to the production center, until the demand of this center is not met, the supply allocation from the supplier will be done based on the lowest transportation cost.

Step 3 At each stage, the capacity of the supplier and the demand of the production center are updated.

Step 4 If the supply capacity or demand of the production center is zero, the priority on the third layer chromosome is reduced to zero.

Step 5 Steps 2–4 continue until the priority of all production centers is reduced to 0.

After decoding the chromosome designed in Fig. 2, all constraints and decision variables are examined and the values of the target functions are determined.

4.5 Comparison indicators of MHAs

Considering the use of three MHAs with different operators, the following comparison indicators have been defined to evaluate the performance of algorithms (Ghahremani-Nahr et al. 2021):

- Averages of objective functions
- Computation time (CPU-time)
- Number of Pareto front (NPF)
- Maximum spread index (MSI)

$$MSI = \sqrt{\sum_{m=1}^{M} \left(max_{i=1:|Q|}f_m^i - max_{i=1:|Q|}f_m^i\right)^2} \tag{31}$$

- Space metric (SM)

$$SM = \sqrt{\frac{1}{|Q|}\sum_{i=1}^{|Q|}\left(d_i - \overline{d}\right)^2} \tag{32}$$

$$\overline{d} = \sum_{i=1}^{|Q|} \frac{min_{k\in Q\cap k\neq i} \sum_{m=1}^{M} \left|f_m^i - f_m^k\right|}{|Q|} \tag{33}$$

- Mean of ideal deviations (MID)

$$MID = \frac{\sum_{i=1}^{n} \sqrt{\left(f_{1i} - f_1^*\right)^2 + \left(f_{2i} - f_2^*\right)^2 + \cdots + \left(f_{mi} - f_m^*\right)^2}}{n} \tag{34}$$

Table 1 The interval limits of the problem parameters based on the uniform distribution function

Value	Parameter	Value	Parameter	Value	Parameter
f_l	~ U [10,000, 12,000]	$d_{c,p}$	~ U [100, 200]	$\xi_{n,n'}$	~ U [10, 20]
h_j	~ U [10000, 12000]	$\psi_{l,p}$	~ U [1000, 1500]	$\xi'_{i,j}$	~ U [10, 20]
g_v	~ U [1000, 1200]	$\varpi_{j,p}$	~ U [1000, 1500]	$\xi''_{j,l}$	~ U [10, 20]
$o_{l,p}$	~ U [5, 7]	γ_v	~ U [500, 600]	u_p	~ U [120, 150]
φ_c	~ U [2, 4]	$k_{n,n'}$	~ U [10, 50]		

Table 2 A set of efficient numerical example solutions with MHAs

Efficient solution	MOGWO		MOALO		NSGA II	
	Z1	Z2	Z1	Z2	Z1	Z2
1	65,234.25	1240.34	64,590.95	1230.78	64,310.82	1232.63
2	66,723.25	1280.64	66,289.98	1257.53	65,508.54	1247.25
3	67,824.62	1342.36	66,943.01	1299.00	66,751.90	1297.85
4	68,824.67	1398.72	67,234.21	1317.54	66,966.98	1310.21
5	69,124.44	1421.35	68,141.02	1394.12	67,170.22	1326.76
6	69,866.47	1494.55	69,155.15	1490.36	67,415.70	1330.99
7	70,234.37	1548.64	70,214.74	1613.80	68,156.96	1402.14
8	71,297.52	1680.37	71,666.49	1846.65	68,920.87	1478.67
9	71,557.64	1724.67	–	–	71,691.01	1804.66
10	71,976.05	1864.77	–	–	–	–

5 Analysis of sample issues

After presenting a mathematical model of SC network with the two objectives of reducing the total network costs and maximizing the freshness of high consumption products, in this section, sample problems in different sizes are analyzed with MOGWO, MOALO and NSGA II. Therefore, first a numerical example is designed and solved and the resulting outputs are examined. The numerical example considered includes 2 types of fast food products in the food sector, 6 customers, 4 distribution centers, 3 production centers, 3 suppliers and 4 types of vehicles. Table 1 shows the interval limits of the problem parameters due to the lack of access to real-world data based on the uniform distribution function.

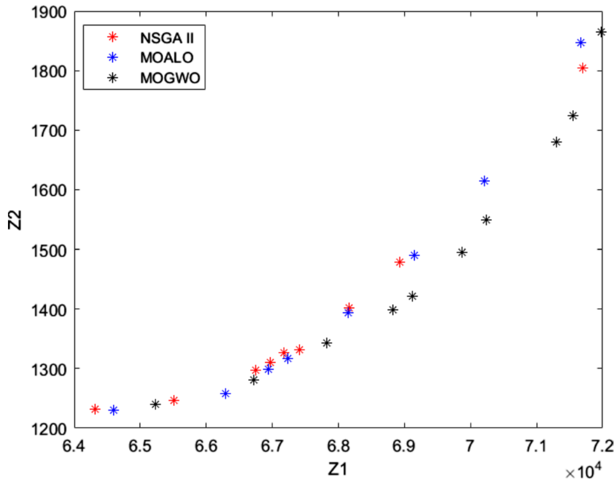

Fig. 3 Pareto front obtained by solving a numerical example with MHAs

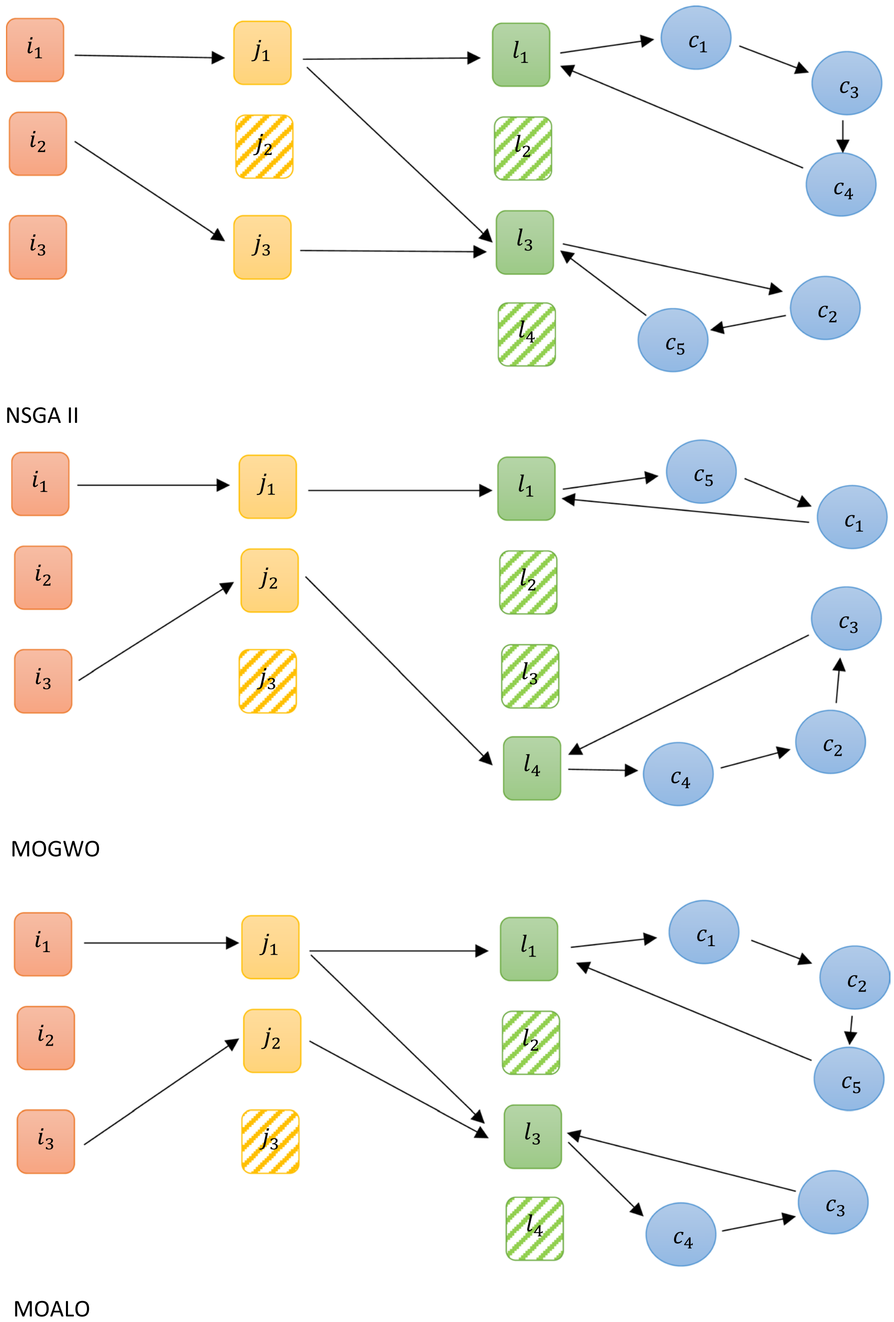

Fig. 4 Location-routing and assignment resulting from solving a numerical example

According to the presented data as well as the dimensions of the numerical example, the efficient solutions obtained from the sample problem are as described in Table 2.

According to Table 2, based on the analysis of efficient solutions, with the increase in the number of vehicles, which leads to an increase in transportation costs and ultimately the total cost of designing the chain network, the quality and freshness of food due to direct delivery from centers. Distribution to customers is increasing. Therefore, with the increase in the number of vehicles in the network, the probability of transmitting COVID-19 virus also increases. Based on the efficient solutions obtained, Fig. 3 compares the Pareto front obtained from different solution methods.

To examine the network structure of the consumer goods SC, Fig. 4 shows the outputs of the first efficient solution obtained from solving a numerical example.

Due to the different number of efficient solutions and the lack of comparing them one by one with each other, the comparison principles of MHAs have been used. Table 3 shows the comparison indices of MHAs in solving numerical examples.

According to Table 3, each of the algorithms performed better than the other algorithms in obtaining one of the indicators. Therefore, it can be said that the NSGA II has obtained the best average of the first objective function, MSI, MID and CPU-Time. The MOGWO has obtained the best mean of the second objective function and the NPF index. Finally, the MOALO performed better than other algorithms in obtaining the SM index. In the following, the sensitivity of the problem under the change of the problem parameter is analyzed. Therefore, it is assumed that the amount of demand varies by 10, 30 and 50%. Hence Fig. 5 shows the changes of this value of the parameter on the values of the objective functions.

According to Fig. 5, it can be stated that with the increase in demand and also the limitation of other parameters of the problem, the construction of more distribution centers and the use of more vehicles has been provided. This has led to an increase in vehicle traffic and the direct distribution of consumer goods to customers. Therefore, the total costs of SC network design have increased. Due to the increase in the number of vehicles and the direct distribution of products, the quality and freshness of the products have been maintained and the value of the second objective function has increased. As the number of vehicles increases due to increased demand, the probability of transmitting the COVID-19 virus also increases. In another analysis,

Table 3 Comparison indicators of MHAs

Index	NSGA II	MOGWO	MOALO
Mean of Z1	67,432.55	69,266.32	68,029.4
Mean of Z2	1381.24	1499.64	1431.22
NPF	9	10	8
MSI	7402.32	6770.65	7102.29
MID	3125.91	4041.08	3448.18
SM	0.479	0.619	0.388
CPU-time	32.18	43.28	45.42

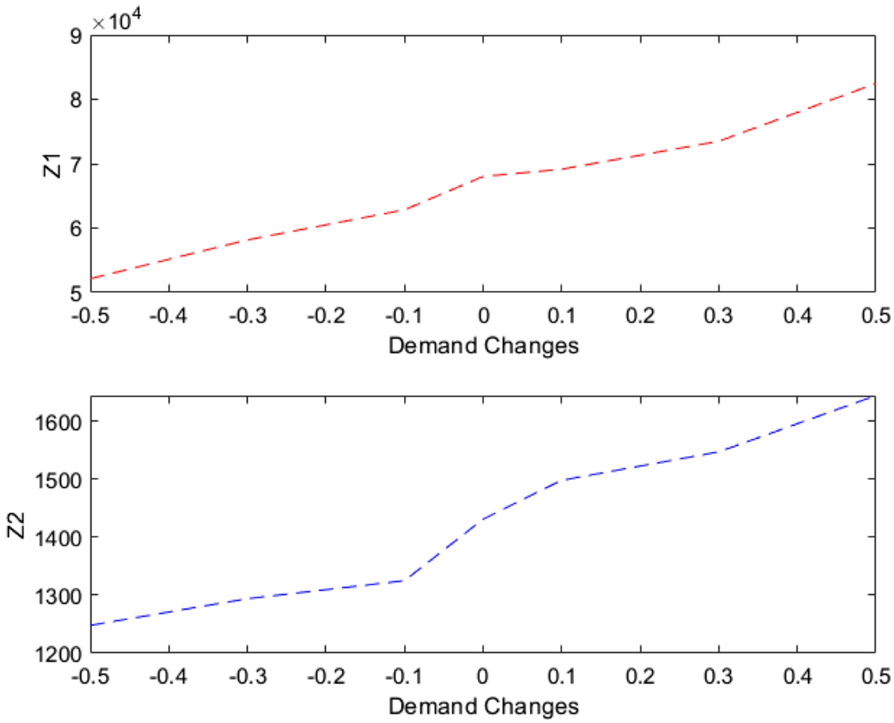

Fig. 5 Changes for demand on the values of the objective functions of the problem

the effect of product shelf life on the values of target functions is investigated. According to the previous analysis, the effect of product shelf life per increase and decrease of 10, 30, 50% has been done in this parameter and the obtained changes in the first and second objective functions are shown in Fig. 6.

According to the sensitivity analysis, it is observed that with increasing the shelf life of products, the freshness of products has increased over time and as a result, the second objective function has increased. However, changes in product shelf life have no effect on SC network design costs.

The efficiency of different algorithms in obtaining different comparison indices has led to the lack of decision-making regarding the ranking of algorithms in solving the SC problem. Therefore, the TOPSIS multi-criteria partitioning method has been used for ranking. In this method, the effect of mean averages of the first objective function, SM, MID and CPU-Time is negative and the effect of mean indices of the second objective function, NPF and MSI is positive. The value of each of the stated indicators corresponds to the data in Table 3. Also, the weight of each index has been obtained using the Shannon Entropy method. By performing calculations, MOALO with a gain weight of 0.6972 is known as the best way to solve the SC problem of consumer goods. The NSGA II and MOGWO also gained the utility weights of 0.6562 and 0.1074, respectively.

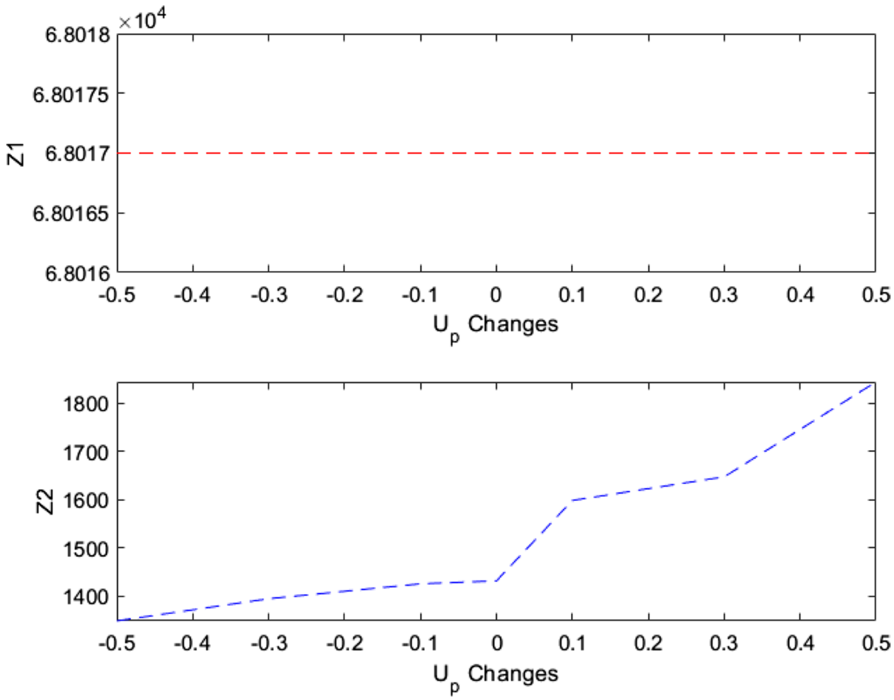

Fig. 6 Changes in the shelf life of products on the values of the objective functions of the problem

After choosing the MOALO as the chosen algorithm in solving the problem of the SC network for fast-moving products, the implementation of the model in a real case study in Iran and East Azarbaijan province has been discussed. This province has 21 cities. The population of this province in 2019 is 4.640 million people, which has grown by 18.67% compared to 2016 (www.amar.org.ir). The increase in population in this province has increased the need to supply fast food. Therefore, this province has been selected for a case study. Figure 7 shows the locations of the cities. In this map, all cities are considered as potential points of distribution centers. Also, the cities of Marand, Shabestar, Azarshahr, Tabriz, Ahar, Sarab, Mianeh, Maragheh, Bonab and Malekan have been considered as potential centers of product production. In this study, all cities are included as demand points.

In this study, two types of perishable products including cooked meat with a perishable time of 2 h and vegetables and fruits with a perishable time of 5–7 days are considered. The shipping cost per kilometer is considered equal to 10 dollars. Also, the cost of building production and distribution centers is estimated at 300,000 dollars. The demand of each city of the province is considered to be between 350 and 1400 units depending on its population. Also, the distance between the cities of the province is shown in Table 4.

After solving the model designed by Heber on the sample problem, 9 effective solutions were obtained as described in Table 5.

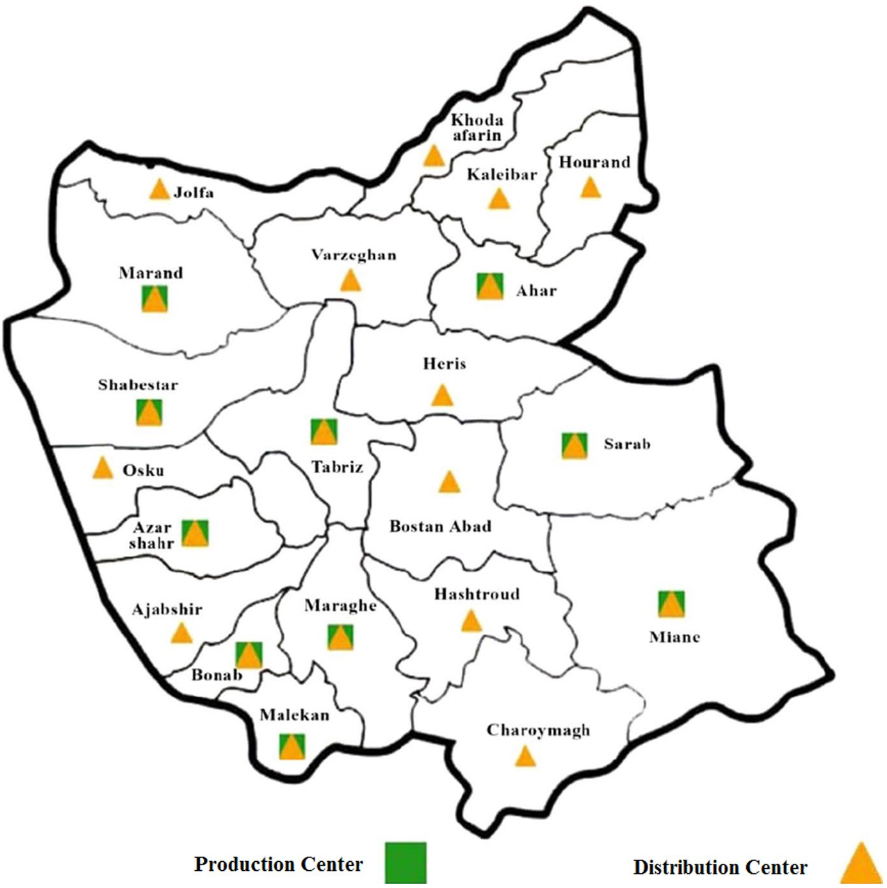

Fig. 7 Map of East Azerbaijan province

According to the results of Table 5, it can be seen that with the increase in the novelty of the products, the costs related to the network design have also increased. Also, in Table 6, the optimal location of production centers and distribution centers is shown based on the first efficient solution obtained.

According to Tables 6 and 4 production centers and 7 distribution centers have been selected to meet the demand of 21 cities in East Azerbaijan Province. Vehicle routing is also shown in Table 7 in the distribution of fast consumption items.

If in the above model, instead of vehicle routing, allocation is used in the distribution of fast consumption items, due to the increase in the number of transports, the network design costs will increase by 15.14%. Meanwhile, the freshness of food also increases correspondingly by 6.12%.

Table 4 Distance between cities of East Azerbaijan province

Distance	Azarshahr	Mianeh	Sarab	Marand	Charoymaq	Bostan Abad	Shabestar	Varzeqan	Heris	Maraghe	Tabriz	Ahar	Kaleybar	Hashtrood	Osku	Jolfa	Khoda Afarin	Hurand	Malekan	Bonab	Ajabshir
Azarshahr	0																				
Mianeh	222	0																			
Sarab	187	98	0																		
Marand	123	239	205	0																	
Charoymaq	218	87	184	235	0																
Bostan Abad	117	106	71	134	113	0															
Shabestar	120	236	205	64	232	131	0														
Varzeqan	147	62	60	161	214	117	62	0													
Heris	147	175	81	161	183	74	131	104	0												
Maraghe	82	176	226	200	107	156	197	223	224	0											
Tabriz	63	174	134	70	171	63	129	98	90	139	0										
Ahar	190	236	133	183	256	102	214	46	61	249	120	0									
Kaleybar	249	299	193	243	316	162	274	228	121	358	180	63	0								
Hashtrood	177	84	132	194	61	62	191	62	131	99	129	200	223	0							
Osku	40	195	162	105	191	92	93	123	122	118	36	145	205	150	0						
Jolfa	186	301	268	67	298	198	126	145	228	263	132	193	252	258	159	0					
Khoda Afarin	294	345	239	289	381	208	309	154	167	371	237	109	46	320	269	298	0				
Hurand	61	164	189	239	84	158	236	104	118	305	176	58	44	220	201	302	89	0			
Malekan	88	197	248	206	129	177	120	232	230	43	146	254	314	120	124	268	377	310	0		
Bonab	63	194	245	180	126	174	117	208	205	21	121	230	290	117	98	244	352	286	24	0	
Ajabshir	41	216	222	158	148	151	155	181	182	42	97	223	283	138	76	220	329	279	48	23	0

Table 5 The set of effective solutions to the real case study

Efficient solution	Z1	Z2
1	3,736,457.64	12,468.48
2	3,816,542.94	13,498.15
3	4,016,456.25	14,162.15
4	4,268,465.26	15,394.22
5	4,434,598.20	16,464.02
6	4,619,466.34	17,694.48
7	4,946,554.02	18,954.31
8	5,319,544.48	20,198.67
9	5,549,844.41	22,984.48

Table 6 The optimal location of the production and distribution centers in the first efficient solution

Supplier	Production center	Distribution center
Tabriz	Tabriz	Ahar
Mianeh	Mianeh	Marand
Marand	Malekan	Tabriz
Ahar	Marand	Sarab
Bonab		Hashtrood
		Bonab
		Azarshahr

Table 7 The optimal route of distribution of fast consuming items in a case study

Start point distribution center	Demand zone	Finish point distribution center
Ahar	Hurand → Kaleybar → Khoda Afarin	Ahar
Ahar	Varzeqan	Ahar
Marand	Jolfa	Marand
Tabriz	Hen Abadris → Bosta	Tabriz
Tabriz	Shabestar	Tabriz
Sarab	Mianeh → Charoymaq	Sarab
Hashtrood	Maraghe	Hashtrood
Bonab	Malekan	Bonab
Azarshahr	Osku	Azarshahr
Azarshahr	Ajabshir	Azarshahr

6 Conclusion

The results of the analysis of the design of the SC network for fast-moving consumer goods in the conditions of Covid-19 show that strategic and tactical decisions must be made correctly in order to reduce costs and maintain the freshness of products.

Examining the efficient solutions obtained from the two-objective model with MHAs showed that with the increase in the novelty of the products, the design costs of the entire network increase. This is due to the use of more vehicles to quickly distribute products to customers. As a result, the fixed costs of using vehicles and the increase in transportation costs lead to an increase in the value of the first objective function. By using the defined function to calculate product freshness, perishability time and product arrival time to customers, it has a significant impact on the freshness of fast consuming products. Due to the existence of different efficient solutions, comparison indices were used. The computational results in a numerical example to examine the performance of the model and solution methods showed that the NSGA II obtained the best mean of the first objective function, MSI, MID and CPU-Time. The MOGWO has obtained the best mean of the second objective function and the NPF index. Finally, the MOALO performed better than other algorithms in obtaining the SM index. Also, all methods of solving in a short time less than 1 min have been able to not solve the nonlinear model, which shows the high efficiency of the three proposed methods. The results also showed that with the increase in demand and also the limitation of other parameters of the problem, the construction of more distribution centers and the use of more vehicles has been provided. This has led to an increase in vehicle traffic and the direct distribution of consumer goods to customers. Therefore, the total costs of SC network design have increased. Due to the increase in the number of vehicles and the direct distribution of products, the quality and freshness of the products have been maintained and the value of the second objective function has increased. Finally, the TOPSIS method was used to rank the algorithms and the indicators used such as means of objective functions, NPF, MSI, SM, MID and CPU-TIME were evaluated as initial indicators. By performing calculations, it was observed that the MOALO with a gain weight of 0.6972 is known as the best way to solve the SC problem of consumer goods. The NSGA II and MOGWO also gained the utility weights of 0.6562 and 0.1074, respectively.

The model presented in this research can be used in industries such as food distribution, food banks, medicines, blood and highly perishable products. Due to the spread of Covid-19 and the need to pay attention to social distancing and avoiding gatherings in stores, it is very important to distribute fast food products on time with vehicles. Therefore, managers and industrial owners, in addition to using the results of the model, due to the consideration of reducing network costs and maintaining the freshness of products, can show their social responsibilities in reducing the spread of the Covid-19 virus. Because in this article, in addition to reducing costs, the preservation of fresh food is also mentioned. Also due to the COVID-19 pandemic, optimal vehicle allocation to reduce the likelihood of virus transmission has been suggested by the FMCG industry. On the other hand, managers can determine the optimal location and number of distribution centers from the results of the model implemented in the real study and determine the optimal route of vehicles in the conditions of Covid-19. The results showed that the implementation of the model in East Azerbaijan province has led to a reduction in routing costs by 15.14% and an descries in product freshness by 6.12%.

Achieving accurate data is one of the biggest limitations in the presented model due to the uncertainty in the real world. Also, obtaining financial data, including costs, is one of the other things that needs clarification. Therefore, for future studies, considering the uncertainty in the amount of demand is due to the very high increase in consumer goods in the household sector is very important. Considering the freshness of food with high perishability in this article, it is suggested to consider the value of food in addition to its freshness to meet customer demand. If there is uncertainty in the demand, it is not possible to produce all the demand; Therefore, it is suggested that in the conditions of a COVID-19 pandemic and not meeting all the demands of customers, the issue of shortage should also be considered in the model. At the end, other MHAs are also proposed to solve and compare with the results of this paper.

Declarations

Conflict of interest The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

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