Iranian Journal of Operations Research
Vol. 11, No. 2, 2020, pp. 24-47
DOI:

Cold multi-cycle supply chain design based on a multi cross-dock system taking into account uncertainty

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The present study aims at designing a cold multi-cycle supply chain based on a multi cross-dock system taking into account uncertainty. In the first step, we identified the factors and variables of the model. In the second, by selecting the study period through designing data collection forms and using the documents reviewing methodologies, the raw data required to measure the final indicators were collected and processed in the project model. Then, they were analyzed considering the research topic and using the techniques of genetic algorithm and particle swarm optimization. The primary objective function is minimizing the cost of transportation and warehousing throughout the supply chain, the second minimizing the total operation time and the number of vehicles within the supply chain, and the third maximizing the product freshness time. Also meta-heuristic optimization methods (strongly adjustable) were adopted to deal with the travel time of suburban vehicles. We also provide an example of the performance of optimization models for a small-sized sample. The computational results showed that longer travel time and further distance do not necessarily increase costs. In fact, it is possible to distribute the products with the right number of trucks at an optimal cost at the right time.

Keywords*: Supply chain, cold multi-cycle, multi cross-dock system, meta-heuristic method, Product freshness cycle.*

Manuscript was received on 08/03/2020, revised on 10/21/2020 and accepted for publication on 12/09/2020-.

1. Introduction

The competitive environment of the international market has highlighted the significance of the supply chain. By mounting pressure on suppliers and distributors to accelerate the delivery of products to customers and the wide diversity of products required by customers globally, companies are trying to develop a distribution strategy and enhance supply chain performance [1]. Today, the supply chain is a central element among economic and manufacturing enterprises, as the customer demand for high quality and fast services has stepped up. Time management in the supply chain leads to fast servicing and greater customer satisfaction, and a major component for the time management is shortening the waiting time. In order to gain and maintain a good position [2] and [3], today's organizations need to use appropriate supply chain management models to achieve competitive advantage and meet customer expectations. Due to the economic, social and environmental challenges that have threatened organizations in the last decade, the customer orientation approach and focus on their demands and designing the organization strategy to create a competitive advantage in organizations has diminished [4]. In this regard, green supply chain management is the newest approach to achieve these goals [5] and [6]. Today, docking operations

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are a supply chain strategy that requires full cooperation and interaction between supply chain members [7]. Researchers have concluded that using a temporary warehouse will reduce the waiting time, i.e., trucks entering the warehouse deliver their cargo directly to the outgoing trucks and limited transitory storage takes place if at all. This concept is called cross-docking [2]. Docking is a modern strategy used in distribution networks to reduce logistics costs as used in today's competitive market. Moreover, many successful implementations of this system have been reported in the present study [8]. Cross-docking is a relatively new distribution and warehousing strategy that is used today in most large companies such as Renault, Toyota, US Post, Wal-Mart chain stores, Amazon online store, etc. The cross dock is an intermediate node in the supply chain that reduces warehousing and maintenance costs [9]. Cross-docking often uses third-party logistics companies to assist with system implementation and management. These companies specialize in simplifying the receipt, sorting and delivery of products from centralized distribution centers. Many companies use these logistics professionals to set up their system and use it for long-term management. Among the necessities of using a cross dock are the following: 1-**Saving storage space**: Although part of the warehouse is dedicated to the classification and integration of goods, but usually not many goods remain in the warehouse and do not need much free space to store goods. 2-**The number of operations and handling of goods in the warehouse is reduced**: unloading, quality control, order sorting and shipping are still done in transit warehouses, but processes such as picking and storage largely disappear. As a result, there is less risk of warehouse goods, because the movement and transportation of goods in your warehouse is reduced [10].

Today, due to the existing research gap regarding the type of modeling and model solving method, we seek a multi-objective, multi-cycle and multi-product model in the green and cold supply chain using multi cross-docking considering the uncertainty of the shipping time of products. Notable, no comprehensive research has been performed in the field of cold supply chain with cross docking. Obviously, the present study seeks to optimize various processes, with different goals in the supply chain in different areas to reduce the cost and time of the delivery various processes.

2. Related work

Supply Chain Network Design (SCND) plays a key role in influencing the environment of supply chains. Supply chain network design models include more elements, such as multiple cycles, decision lists, transport modes, and operations-related practices to better illustrate reality, which complicates matters [11]. In designing a supply chain, strategic decisions are made about the location of facilities (factories, distribution centers, warehouses and customer access points), capacity, production capacity and inventory capacity, and supply and delivery channels [11]. Supply chain management includes all plans, initiatives and management activities that effectively control the management and improvement of supply chain operations. The main components of the supply chain, in terms of suppliers and customers, are provided in the following chart [12] :

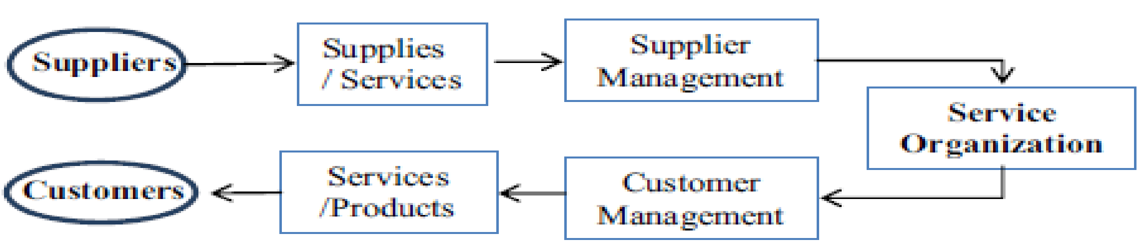

Figure 1. The main components of the supply chain in terms of suppliers and customers

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The purpose of this combination, which determines the chain configuration, is to produce and distribute products in the right amount, time and place [13]. Entrepreneurs who design the supply chains to implement new products or technologies must determine the overall scale of the company and control the amount of economic activity at each stage of the process [14] and [15]. A supply chain is a network of facilities that undertakes activities such as the supply of raw materials, conversion of these materials into semi- and fully-manufactured products, and the distribution of these manufactured goods among customers. Supply chain management involves coordination of manufacturing process, inventory, and transportation between components of a supply chain to achieve the best possible combination of responsiveness and efficiency for the market that feeds it. The five main components of the supply chain are as follows [16].:

2.1. Cross docking

Docking operations pioneered the US transportation industry in the 1930s. The U.S. military used docking operations in the 1950s, and Wal-Mart began such operations in the retail sector in the late 1980s [17]. Docking reduces long-term storage and is therefore suitable for perishable products, specifically those that decompose and have a short shelf life [18]. Docking involves transporting incoming cargo directly to outgoing vehicles without storing them. In this manner, transferring takes less than 24 hours. The main benefits of this practice are the reduction of maintenance costs, order collection and transportation, as well as the reduction of delivery time in supply chains [19]. Many researchers have studied the integration of vehicle routing with different distribution strategies to deal with real-world applications and logistics systems. One recent application of this approach is to integrate this problem with the docking problem. The table shows some types of vehicle routing problems studied over the years [20].

Table 1. An overview of the types of vehicle routing problems

Introduced by:	Short definition	Type of routing problem of the vehicles
Dantzig and Ramser [21]	Products are delivered by vehicles with limited capacity.	Capacitated VRP
Cooke and Halsey [22]	The travel time between customers and the warehouse depends on the distance and time of day (e.g., peak hours, weather conditions).	Time Multiple Depot VRP
Tillman [23]	There is more than one warehouse and each customer is identified by the vehicle associated with one warehouse unit.	Multiple Depot VRP
Dror and Trudeau [24]	Each customer can be visited by more than one vehicle.	Split Delivery VRP
Beltrami and Bodin [25]	Planning for time periods: Visiting customers in different days	Periodic VRP
Tillman [23]	Some factors such as demand and travel time are not known.	Stochastic VRP
Russell [26]	Customers must be visited by vehicles in a limited and specified period without deviation.	VRP with time windows
Speidel [27]	There is scheduling online routing according to dynamic requests.	Dynamic VRP
Cheng et al.	Some factors, such as demand and time windows,	Fuzzy VRP

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[28]	are ambiguous and must be defined by fuzzy logic.	
Alinaghian et al. [29]	A mathematical model for Green Inventory-Routing Problem with Time Windows (GIRP-TW) using a piecewise linearization method	GIRP-TW
Babaee Tirkolaee et al. [30]	A multi-trip capacitated arc routing problem under fuzzy demands for urban solid waste management was presented	An arc routing problem
Tirkolaee et al. [31]	The Pollution-Routing Problem with Cross-dock Selection (PRP-CDS) where the products are processed and transported through at least one cross-dock was presented	Considering traffic conditions in transportation PRP
Tirkolaee et al. [32]	A robust green traffic-based routing problem for perishable products distribution	Considering traffic conditions in transportation
Tirkolaee et al. [33]	A sustainable multi-trip location-routing problem with time windows for medical waste management in the COVID-19 pandemic is presented	MTLRP-TW

The research gaps are as follows:

1- Not paying attention to considering several meta-heuristic algorithms and comparing them with each other

2. Lack of attention to Product freshness cycle in previous research

3- Lack of considering the model as multi-period and multiple cross-dock with uncertainty at the same time

4- Not paying attention to minimizing costs and minimizing operating time and maximizing the shelf life of the product simultaneously

Therefore the proposed innovations include the following:

1- Solve the proposed model using two meta-heuristic algorithms including NSGA-II and MOPSO and compare them with each other

2- Considering Product freshness cycle in the proposed model

3-Presenting multi-cycle, multi cross-dock multi-echelon and multi period model considering demand uncertainty

4- Minimizing transportation and warehousing costs, minimizing the total operation time within the supply chain and maximizing the shelf life of the product simultaneously

3. Mathematical model

To better understand and explain the research problem, the flow of operations in the supply chain is plotted below. In this figure, the flow of distribution and transportation operations of several intersection docks and a number of customers and suppliers are considered. Transportation vehicles with different capacities have also been used to transport products in the supply chain.

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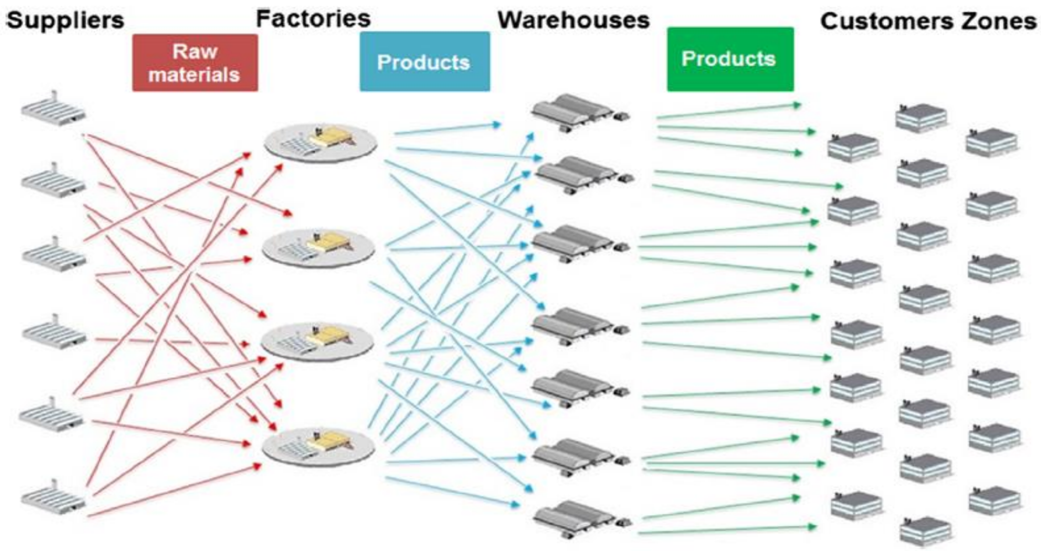

Figure 2. Transport method in cross dock

As mentioned before, docking is a powerful innovative warehousing strategy in controlling distribution and logistics costs, which, at the same time, maintains the customer servicing level. Shipments typically remain in the dock for less than 24 hours. Sometimes, this time is less than an hour, so cross-docking not only provides timely delivery but also offers advantages over traditional warehousing, such as reducing inventory capital, decreasing storage space, lowering transportation costs and shortening a work cycle time. Cross-docking also accelerates financial flows as it speeds up the movement of inventories.

In fact, in this problem, after loading the products from the suppliers, the incoming trucks move directly toward the customers or toward another supplier or a cross dock to unload the products. They are, then loaded onto output trucks and transported to customers. It should also be noted that a truck can load products from more than one supplier, and it can move to several customers and unload products. Several trucks with different capacities can be used to transport products. In this research, the problem has two opposite objective functions and a number of constraints, so we evaluate three objective functions simultaneously using genetic algorithms and particle swarm to obtain the best overall solution.

- The primary objective function is to minimize transportation and warehousing costs throughout the supply chain.
- The second objective function is to minimize the total operation time within the supply chain and the number of traveling trucks.
- The third objective function is to maximize the shelf life of the product.

Table 2. Model parameters and variables

	Descriptions
Indices	
K	Set of cross docks (k=1,2,3,…., c)
I	Set of supplier
P	Set of products (p=1,2,3,…,g’)

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T	Set of times (t = tmin , …. , tmax)
T’	Set of periods
H	Set of vehicles in the loading process (h=1,2,3,…,H)
H’	Set of vehicles in the delivery process(h=’1,2,3,…,H)
R	Set of loading nodes
γ	Set of delivery nodes
B	Set of supplier nodes (i=1,2,3,…,n)
L’	Set of selling agents (agent)
G	Set of activities (g=1,2,3,…,G)
Parameters	
C_{ijh}	Cost of shipping from supplier *i* to supplier *j* by truck *h*
$Dist_{ijh}$	Distance of the node *i* to *j* by truck *h*
$x_{ijhtt'}$	If truck *h* goes from supplier *i* to supplier *j* in time *t*, then t'=1, otherwise t'=0
$x^{i'}_{pktt'}$	If , in the loading process, the product *p* goes from node *i'* at time *t* and to the cross dock *k* in time period t, then t' = 1 Otherwise t'= 0
$Dist_{i'k}$	Node distance *i'* (in loading process) from the cross dock *k*
$C_{i'k}$	Shipping cost from node *i'* (harvesting process) to cross dock *k*
$x''^{il}_{ptt'h'}$	If product *p* in the delivery process goes from node *i''* (in cross dock) at time *t* and period *t'* to customer, then L = 1 Otherwise L= 0
$Dist_{i''k}$	Node distance *i''* in the process of delivery to the cross dock *k*
$C_{i''k}$	Shipping cost from node *i''* (delivery process) to cross dock *k*
α	Early arrival penalty (Rials per pallet per minute)
β	Late arrival penalty (Rials per pallet per minute)
e_l	Time of early arrival to customer *l*
ta_L	Time of late arrival to customer *L*
D_{pL}	The product *p* ordered by customer *L* (in pallets)
$FC_{h'}$	Fixed cost of using vehicle *h’*
FC_h	Fixed cost of using vehicle *h*
$\in_{h'}$	If vehicle *h’* is used
$\in_h$	If vehicle *h* is used
$HC_{kpt'}$	Cost of maintaining each unit of product *p* based on the time at the dock *k* in the time period *t'*
$S_{pktt'}$	Amount of product *p* at the cross dock *k* at time period *t'* at time *t*
$\rho^{p}_{L'gk}$	Cost of coordination of activity *g* for product *p* in case of assignment of activity to representative L' in cross dock *k*
$\rho_{L'gk}$	Cost of processing of activity *g* for product *p* in case of assignment of activity to representative *L'* in cross dock *k*
scs_{gk}	Cost of coordination resulting from the integration of activities in the set *g* in the cross dock *k*
$y^{p}_{L'g}$	If the activity *g* of product *p* is performed by factor *L'*, then = 1 Otherwise = 0
Z_g	If a product is merged with a sequence of activities *g* into a set *g* by a specific agent.
q''_{iph}	Amount of product *p* loaded by supplier *i* using vehicle *h*

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$\boldsymbol{\omega_{i'h}}$	Time of entry of vehicle *h* to supplier *i'* in the process of loading and cross docking
$\boldsymbol{\omega_{i''h'}}$	Time of entry of vehicle h*'* to supplier *i''* in the process of loading and cross docking
$\boldsymbol{d_{i'i''}}$	Distance between (supplier / customer) *i'* and (supplier / customer) *i''*
$\boldsymbol{th_{ijh}}$	Time of shipping from supplier *i* to supplier *j* by truck *h*
$\boldsymbol{th_{i'k}}$	Time of shipping from supplier *i'*to cross dock *k*
$\boldsymbol{A_{ihp}}$	Time of loading of each unit of product *p* from supplier *i* in truck *h*
$\boldsymbol{e_{i'k}}$	Time of early arrival of truck *h* to cross dock *k*
$\boldsymbol{ta_{i'k}}$	Time of late arrival of truck *h* to cross dock *k*
$\boldsymbol{V_{i'j'hk}}$	If node *i'* precedes *j'* in loading process by truck h = 1and cross dock *k* Otherwise = 0
$\boldsymbol{V_{i''j''h'k}}$	If node *i''* precedes *j''* in loading process by truck *h* = 1 cross dock *k* Otherwise = 0
W_p	Priority of freshness of product type (p) which is in fact the relative weight importance of freshness of product type (f)
fr_{iip}	Freshness of product type (p) ordered by customer *I* upon delivery to customer (the fresher the product = 1, otherwise = 0) 0≤friip ≤1
D_{iip}	Amount of product type (p) ordered by customer *I* (in pallets)
Variables	
frs_{iip}	Infinite variable in terms of sign; This is an auxiliary variable used to model the partial linear performance of freshness
δ_{iip}	Binary variable, iip = 1 if frsiip <1 otherwise iip = 0
fl_p	Freshness and durability of product type *p* (in minutes)
M	Large number (penalty)
s_{ii}	Customer order delivery time *ii*
r_{ii}	Customer order dispatch time *ii*

$$Min\ TC = \sum_{t'=1}^{T}\sum_{k=1}^{C}(F_k + oc_{kt'}) + \sum_{i}^{n}\sum_{j}^{m}\sum_{h}^{H} C_{ijh}x_{ij}Dist_{ij} + \sum_{t'=1}^{T}\sum_{P=1}^{q'}\sum_{i'=1}^{n'}\sum_{k=1}^{c}\sum_{t=Tmin}^{Tmax} X_{pktt'}^{i'}Dist_{i'k}C_{i'k} + \sum_{t'=1}^{T}\sum_{P=1}^{q'}\sum_{i''=1}^{m}\sum_{k=1}^{c}\sum_{t=Tmin}^{Tmax} X_{pkt't}^{i'}Dist_{i''k}C_{i''k} + \sum_{l=1}^{L}\alpha D_l\tilde{e}_l + \sum_{l=1}^{L}\beta D_l\widetilde{ta}_l + \sum_{h=1}^{H} Fc_h\rho_h + \sum_{h'=1}^{H'} Fc_{h'}\rho_{h'} + \sum_{t'}^{T}\sum_{h}^{c}\sum_{p}^{q'}\sum_{t=Tmin}^{Tmax} HC_{hpt'}S_{pktt'} + \sum_{l'=1}^{L'}\sum_{g=1}^{G'}\sum_{p=1}^{q'}(r_{l'g}^{p} + P_{l'g}^{P}) * Y_{l'g}^{P} - \sum_{q} scsqZ_q \quad (1)$$

Cost minimization = cost of locating cross-docks k + cost of transport from supplier to supplier + (cost of loading * distance * cost of transport) + (cost of delivery * distance * cost of transport) + (fixed cost of trucks used) + (demand * early arrival * cost of early arrival) + (cost of late arrival * demand * late arrival) + (maintenance fee based on time * demand) + (coordination fee + processing fee) agent – integration fee

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Model 2: Time minimizati

$$minT = \sum_{h}^{H}\sum_{i}^{n}\sum_{j}^{m}\widetilde{th}_{ijh}x_{ijh} + \sum_{t'=1}^{T}\sum_{t=Tmin}^{Tmax}\sum_{i'}^{n'}\sum_{h}^{c}\widetilde{th}_{i'k}x_{phtt'}^{i'} + \sum_{k}^{c}\sum_{h}^{H}\sum_{t=Tmin}^{Tmax}\sum_{t'=1}^{T}ul_{kph}D_{L}x_{pktt'}^{i'} + \sum_{i}^{n}\sum_{j}^{m}\sum_{h}^{H}\tilde{A}_{ijhp}x_{ijh}q''_{iph} + \sum_{t'=1}^{T}\sum_{h}^{c}\sum_{h'}^{H'}\sum_{tmin}^{tmax}u_{kph'}D_{L}x_{pktt'}^{i'} + \sum_{t'=1}^{T}\sum_{k}^{c}\sum_{l}^{L}\sum_{h'}^{H'}\sum_{tmin}^{tmax}\widetilde{th}_{klph'}x_{phtt'}^{i''} + \sum_{i'}^{m}\sum_{k}^{c}\sum_{i'}^{n'}\sum_{h}^{H}\sum_{j'}^{m'}(\tilde{e}_{i'kh} + \widetilde{ta}_{i'})V_{i'j'hk} + \sum_{i''}^{n'}\sum_{j''}^{m'}\sum_{h'}^{H'}\sum_{k}^{c}\sum_{l}^{L}(\tilde{e}_{l} + \widetilde{ta}_{l})V_{i''j''h'k} \tag{2}$$

Time minimization = Time of shipping from supplier i to supplier j + Time of shipping from supplier to cross dock + unloading time (quantity) + initial loading time + reload time + time of shipping from cross dock to customer + (late arrival time + early arrival time) (if shipping ....)

Notably, in this study, a simple linear model comparable to the model proposed by Osvald and Stirn has been adopted to estimate the reduction in the freshness of the products. It is assumed that each perishable product has specific freshness conditions that can be divided into three stages. The product's best freshness is at point t = 0, which is generally at the time of production or loading. In the first stage, when freshness is considered constant (from 0 to A in Fig. 1), no significant change in product freshness is observed. Here, we assume that at this stage the product has an initial freshness from the time of product arrival until that time. Then, when fresh produce is harvested or imported from foreign countries, it is first delivered to distribution centers such as cross dock and then delivered to the end consumers. Importantly, insulated vehicles, such as refrigerated trucks, are commonly used for road and international transportation, and non-insulated vehicles are used for final distribution (i.e., from cross-docks to customers), which are mostly used for urban transportations. Therefore, we assume that when products are not loaded at the dock, they are just as fresh as harvest time because they are brought into the cross dock using refrigerated trucks that can use cooling equipment to adjust the internal temperature. In fact, some shipping companies also work with refrigerated trucks for the final distribution of their products; however, refrigerated trucks are more expensive and consume more fuel than non-refrigerated trucks. The proposed model could be easily extended to include refrigerated trucks to distribute products after cross-docking [18].

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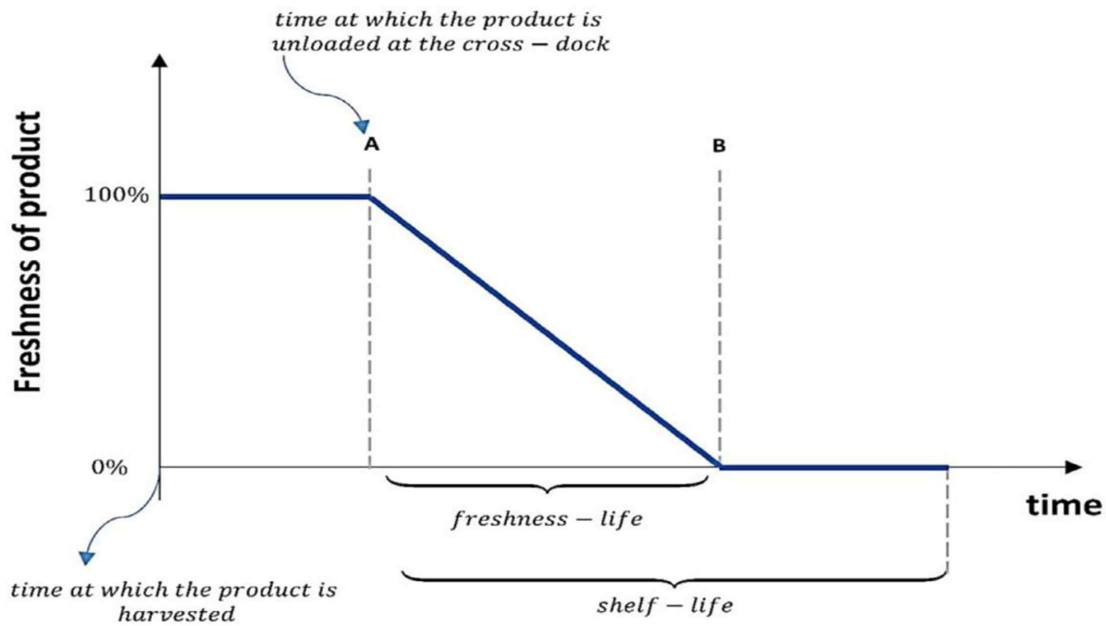

Figure 3. Product freshness cycle

The first stage ends when the product stops at the dock (point A) and then the freshness of the product at point A begins to change significantly. In the second stage (from A to B), which is accompanied by the loading of the product in the cross dock and the customer delivery process, the freshness decreases over time and at point B, it will be equal to zero. Since the freshness is zero, unlike Osvald and Stirn, we assume here that this product is acceptable to the customer even if it is not fresh. This is because the shelf life of the product is much longer than the required distribution time. In addition, the weather conditions for a particular season can be considered almost stable [18]. Now, based on the above, the model of freshness is as follows:

$$\max F = \sum_{p=1}^{P} \sum_{ii=1}^{n} W_p fr_{iip} D_{iip} \tag{3}$$

above, the model of freshness is as follows:

Maximum freshness = Priority of freshness of product type (p) which is in fact the relative weight of freshness of product type (p) * freshness of product type (p) ordered by the customer *ii* upon delivery to the customer * amount of product type (p) ordered by the customer *ii* (in the form of a pallet)

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3.1. Constraints of the study

Constraints of this study are:

$$\sum_{t'=1}^{T}\sum_{t=Tmin}^{Tmax}\sum_{i}^{n}\sum_{h}^{c} x_{ijtt'} = 1 \qquad \forall\, i.j \;\in B \tag{4}$$

1. Each node in the loading process receives service from only one vehicle.

$$\sum_{p}^{q'}\sum_{t=Tmin}^{Tmax}\sum_{k}^{K}\sum_{t}^{T} x_{pktt'}^{i'} = 1 \qquad \forall\, i \;\in B \tag{5}$$

2. Each route in the loading process is driven by a vehicle.

$$\sum_{k=1}^{c}\sum_{tmin}^{T-1} x_{pktt'}^{i''} = 0 \qquad \forall\, i''.p\,.t' \tag{6}$$

$$\sum_{k=1}^{c}\sum_{t=T}^{T+1} x_{pktt'}^{i''} = 1 \qquad \forall\, i''.p\,.t \tag{7}$$

$$\sum_{k=1}^{c}\sum_{T+1}^{Tmax} x_{pktt'}^{i''} = 0 \qquad \forall\, i''.p\,.t' \tag{8}$$

3 , 4 , 5. Ensures that each type of delivery, if necessary, takes place in a specific time window, and outside that range takes a value of zero in each time period.

$$\sum_{p=1}^{q'}\sum_{k=1}^{K}\sum_{t=tmin}^{tmax}\sum_{t'=1}^{T} s_{pktt'} = D_L \tag{9}$$

6. The amount of product that goes to the customer from the cross dock is equal to the customer's demand.

$$\mathrm{s}_{\mathrm{pkt'tmin}} = 0 \tag{10}$$

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7. It shows the initial inventory of each product in the cross dock.

$$\sum_{p=1}^{q\prime}\sum_{k=1}^{K}\sum_{t=tmin}^{tmax}\sum_{t'=1}^{T}\sum_{h\prime}^{H\prime} x_{ptt\prime h\prime}^{i\prime\prime} = 1 \qquad \forall\, i.j\ \in B \tag{11}$$

8. It indicates that each node in the delivery process receives service by only one vehicle.

$$x_{phtt\prime}^{i}\,.x_{phtt\prime}^{i\prime}\,.\ x_{phtt\prime}^{i\prime\prime} \le\ x_h \tag{12}$$

9. The transport of product p from supplier to cross dock and from cross dock to retailer in delivery and loading processes takes place in each time period t' only when cross dock k is established.

$$V_{i'.j'.h.k}\ \ .V_{i''.j''.h.k}\quad \in\quad \{0\,.\,1\} \tag{13}$$

$$N_{i'.h}\,.N_{i''.h}\ \ \ge\ \ 0 \tag{14}$$

10, 11. It indicates binary and non-negative decision variables.

12. It indicates the first part of the freshness function in the figure (from A to B) and expresses the freshness as a linear reduction function from the start of loading the products in the cross dock.

$$frs_{iip}fl_p \le\ fl_p - (\ s_i -\ r_i\ ) \tag{15}$$

13. Determines whether the type of product ordered by the customer will be delivered when it is fresh.

$$frs_{iip} + M\delta_{iip}\ \ge 0 \tag{16}$$

14, 15, 16. It indicates the freshness in (after B) and ensures that the freshness of products delivered to customers may equal zero.

$$fr_{iip} \ge\ frs_{iip} \tag{17}$$

$$fr_{iip} \le frs_{iip} + M\delta_{iip} \tag{18}$$

$$fr_{iip} \le 1 -\ \delta_{iip} \tag{19}$$

In this study, the triangular method has been used for the defuzzification of the functions. Here, the validity of a fuzzy event, average possibility and the obligation of that event are defined. A fuzzy event may fail, even if its probability of occurrence is equal to one, and it may occur even if the requirement is zero. For this reason, the validity criterion uses a combination of these two

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functions and basically plays the role of probability of occurrence in fuzzy conditions. For the time variable, a triangular fuzzy number is used, which is a general assumption. Therefore, for time, consider the fuzzy number T = (t1.t2.t3) and its membership function as follows:

$$\mu_T(x) = \begin{cases} \frac{x-t_1}{t_2-t_1} & t_1 \le x \le t_2 \\ 1 & x = t_2 \\ \frac{t_3-x}{t_3-t_2} & t_2 \le x \le t_3 \\ 0 & x = t_3 \end{cases} \tag{20}$$

Accordingly, the time of arrival of the truck to the customer or cross dock and the time of moving the truck between two points is not less than t1 or more than t3, and t2 is the most reasonable time. Therefore, in this paper, time is considered as a fuzzy number with a triangular membership function and based on the above definitions, the functions of possibility, obligation and validity are rewritten as follows:

$$Pos\,\{T \ge r\} = \sup \mu\,(u) = \begin{cases} 0 & \mathrm{r} \ge \boldsymbol{t_3} \\ \frac{\boldsymbol{t_3}-r}{\boldsymbol{t_3}-\boldsymbol{t_2}} & \boldsymbol{t_2} \le r \le \boldsymbol{t_3} \\ 1 & r \le \boldsymbol{t_2} \end{cases} \tag{21}$$

$$Nec\,\{\mathrm{T} \ge r\} = \begin{cases} 0 & \mathrm{r} \ge \boldsymbol{t_2} \\ \frac{\boldsymbol{t_2}-r}{\boldsymbol{t_2}-\boldsymbol{t_1}} & \boldsymbol{t_1} \le r \le \boldsymbol{t_2} \\ 1 & r \le \boldsymbol{t_1} \end{cases} \tag{22}$$

$$Cr\,\{\mathrm{T} \ge r\} = \begin{cases} 0 & \mathrm{r} \ge \boldsymbol{t_3} \\ \frac{\boldsymbol{2t_2-t_1-r}}{2(\boldsymbol{t_2}-\boldsymbol{t_1})} & \boldsymbol{t_1} \le r \le \boldsymbol{t_2} \\ \frac{\boldsymbol{t_3-r}}{2(\boldsymbol{t_3}-\boldsymbol{t_2})} & \boldsymbol{t_2} \le r \le \boldsymbol{t_3} \\ 1 & r \le \boldsymbol{t_1} \end{cases} \tag{23}$$

Thus, it can be said that the expected value of the fuzzy time variable is as follows

$$E\,(T) = \int_0^{\infty} Cr\,\{\mathrm{T} \ge r\}dr - \int_{-\infty}^{0} Cr\,\{\mathrm{T} \le r\}dr \tag{24}$$

4. Solution methodology

The solution methodology including NSGA-II and MOPSO are as follows:

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4.1. NSGA-II algorithm

Genetic algorithm with non-dominated sorting becomes one of the most suggested and widely used optimization algorithms in the field of multi-objective optimization. This algorithm was introduced by Deb in 2002. This algorithm and its unique approach to multi-objective optimization problems have been used repeatedly by different people to create multi-objective optimization algorithms. Figure 1 shows a chromosome representation.

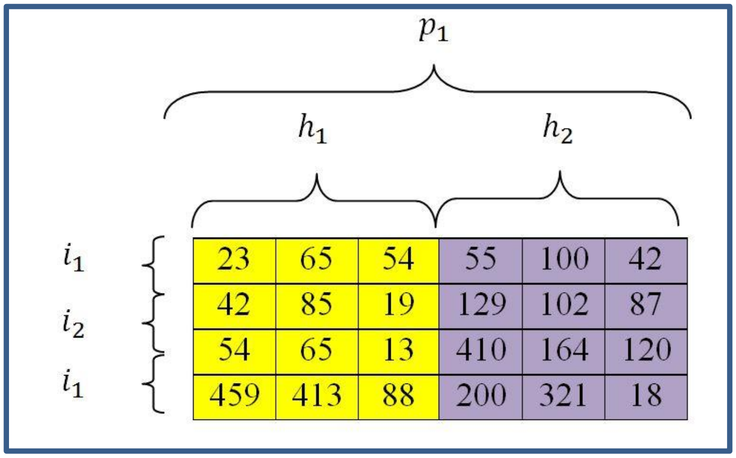

Figure 4. Chromosome representation

The cross-over considered in this research is two points. In this way, 2 points are randomly selected and genes are transferred. The cross-over considered in this research is swap by selecting a string at random and reversing the corresponding genes. The stopping criteria are defined as follows:

- Sometimes, computing time is considered as a criterion to stop the algorithm.
- Sometimes this criterion is based on the extent of the dispersion of genes within the population.

Finally the NSGA-II parameters are as follows:

Table 3. The parameters of NSGA-II algorithm

Population	Crossover Rate	Mutation	Max Iteration
100	0.4	0.04	100

4.2. MOPSO algorithm

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The first multi-objective version of the Particle Swarm Optimization algorithm was introduced in 1999 by Moore and Chapman [38]. In this algorithm, an elitist policy is used in order to keep the results superior and dominant in the iterations of the algorithm. Dominant responses are stored in external archives.

In MOPSO algorithm, the equations describing the particle behavior are as follows. Equations 11 and 12 determine the velocity and location of the i-particle at moment t + 1.

$$V^i[t+1] = wV^i[t] + c_1 r_1\left(x^{i,best}[t] - x^i[t]\right) + c_1 r_1\left(x^{g,best}[t] - x^i[t]\right)$$

$$x^i[t+1] = x^i[t] + V^i[t+1]$$

Where $x^i[t]$ is the position of particle i at moment t, $V^i[t]$ is the velocity of particle i at moment t, $x^{i,best}[t]$ is the best position of particle i at time t. Also, the coefficient of inertia, $r_1$and $r_2$are random numbers between zero and one with uniform distribution, $c_1$and $c_2$are the coefficients of individual and collective learning, respectively.

The criterion for stopping the implementation of the particle group algorithm is the number of iterations. This maximum number of iterations is considered equal to 500 for all problem modes.

5. Computational results

First, to solve the above model, the definite model is considered and the results are examined. Then, according to the research topic and using two techniques, genetic algorithm and particle swarm optimization are used. This study uses genetic algorithm and particle swarm optimization for evaluation. In this study, the model is solved using MATLAB 2015 software and Core i7 computer with 8 GB of RAM. Here, to validate the model, methods of weighted sum and goal programming have been used in three cases and the solutions have been compared. Before that, however, the model parameters are as follows:

Table 4. The value of the model parameters

K	3	R	5
P	5	γ	12
T	(30 , 180) min	B	3
T’	(1, 5)	L’	12
H	(5, 10)	G	4
H’	(5, 10)	α	0.1
D_L	(1 , 10)	β	0.33
$Dist_{ijh}$	50 – 350 km	$Dist_{i'k}$	50 – 350 km
$Dist_{i''k}$	50 – 350 km	$FC_{h'}$	4$
FC_h	$ 4	$HC_{kpt'}$	$ 10
q''_{iph}	10 / 2000	$\rho^{p}_{L'gk}$	**$**1
scs_g	**$**1	$\rho_{L'gk}$	**$**1

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Before solving with metaheuristic methods with high default values, the solution set can be achieved using the two methods of weighted sum and goal programming. The set of optimal solutions is as follows:

Table 5. Solve numerical results

NO.	Weighted Sum			Goal Programming			RunTime	
	F_1	F_2	F_3	F_1	F_2	F_3	W	G
1	8.14567332 e^{+10}	1.018922e^{+2}	1.926e^{+5}	8.0388431 e^{+10}	1.0912202 e^{+2}	1. 213e^{+5}	3.3	50.32
2	8.1474357 e^{+10}	1.020118e^{+2}	1.398e^{+5}	8.0644122 e^{+10}	1.1284526 e^{+2}	1.292 e^{+5}	3.9	4.94
3	8.153335e^{+10}	1.030215e^{+2}	1.987e^{+5}	8.0739139 e^{+10}	1.0743586 e^{+2}	1.718 e^{+5}	5.1	5.48
4	8.1545635 e^{+10}	1.04023298 e^{+2}	2.275e^{+5}	8.0783154 e^{+10}	1.0639453 e^{+2}	2.091 e^{+5}	3.94	5.87
5	8.1574675 e^{+10}	1.04027012 e^{+2}	2.466e^{+5}	8.0934584 e^{+10}	1.0682434 e^{+2}	2.234 e^{+5}	4.31	5.64
6	8.5136032 e^{+10}	1.0503593 e^{+2}	2.554e^{+5}	9.3494611 e^{+10}	1.0548101 e^{+2}	2.404 e^{+5}	5.38	6.92
7	8. 719478e^{+10}	1.0511343 e^{+2}	2.582e^{+5}	9.368342 e^{+10}	1.0586424 e^{+2}	2.489 e^{+5}	5.18	5.84
8	8. 926354e^{+10}	1.0553567 e^{+2}	2.634e^{+5}	9.3900345 e^{+10}	1.0646834 e^{+2}	2.587 e^{+5}	5.33	6.41
9	9.0214561 e^{+10}	1.0590129 e^{+2}	2.723e^{+5}	9.4139563 e^{+10}	1.0635952 e^{+2}	2.639 e^{+5}	5.93	7.38

Now, according to the above assumptions, we will solve the problem on a small scale in order to produce the initial population. We first use the Taguchi method to adjust the parameters. In this study, the most suitable design is three-level experiments, and according to the Taguchi standard orthogonal arrays, the L9 array has been selected as the appropriate experimental design to parameterize the proposed algorithms. The L9 array is an experimental design with 9 runs. The results are as follows:

Table 6. Experiment and Taguchi output

Output			**nIt (D)**	**Pm (C)**	**Pc (B)**	**nPop (A)**	**No**
Z1	Z2	Z3					
8.35E+11	2.90E+03	23472304	100	0.1	0.7	100	**1**
7.25E+11	1.35E+04	245534.1	170	0.2	0.7	150	**2**
7.48E+11	1.64E+03	2430963	170	0.1	0.8	150	**3**
7.36E+11	1.36E+04	2749175	200	0.3	0.7	160	**4**

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7.40E+11	2.32E+03	2329746	200	0.3	0.7	160	**5**
7.43E+11	1.15E+03	2223634	150	0.3	0.7	200	**6**
7.61E+11	2.99E+03	2674282	150	0.3	0.7	200	**7**
8.37E+11	3.14E+03	2881688	170	0.1	0.9	200	**8**
8.36E+11	3.11E+03	2832694	200	0.2	0.8	200	**9**

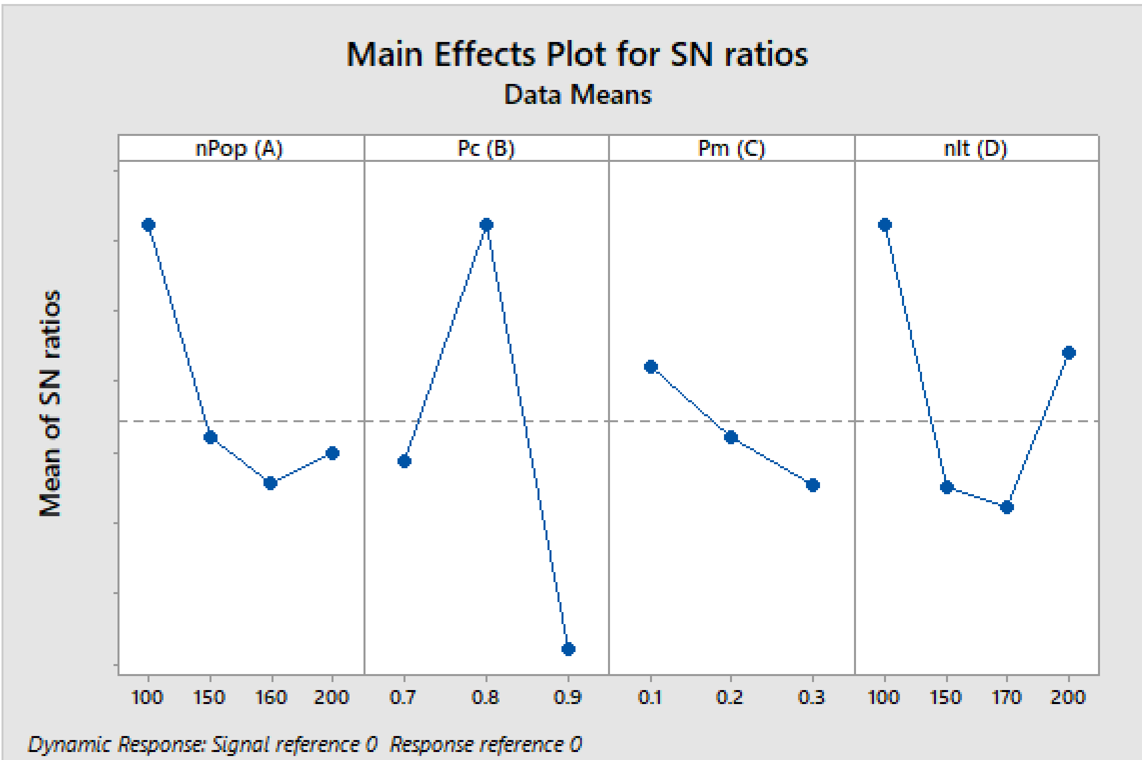

Figure 5. Taguchi output

Hence, any parameter at a higher level is selected. Finally, according to the results, the values of the parameters of the NSGA II algorithm are given in the following table:

Table 7. Parameter values of NSGA II and PSO algorithms

Population	**Cross over rate**	**Mutation Percentage**	nIt (D)
200	0.7	0.2	180

Accordingly, any parameter at a higher level is selected. Specifically, we used the above formula for the Taguchi method, i.e., "the less, the better". The result obtained with this method is S/N, and the higher the S/N value, the better. The parameters of the NSGA II algorithm are given in the following table:

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Table 8. Parameter values of NSGA-II algorithm

Population size	**Number of generation**	**Fraction**	**Cross over rate**	**Mutation Percentage**	**Mutation rate**	**Cross over Fraction**
200	180	0.21	0.7	0.2	0. 03	0.7

Since the model presented in this research is a two-objective model, the Lp metric method, and in particular the L1 metric method, is used to convert the model into a single-objective model. According to the L1 metric method, in the first step, the problem is solved by considering each of the two objectives separately in order to achieve optimal solutions, from F1 and F2. Next, we used a linear equation to minimize the distance from the values obtained. The following results are obtained when the functions are executed in the algorithm until the stop command is reached:

Table 9. Algorithm comparison NSGA-II and MOPSO

NO.	**NSGA II**			**MOPSO**		
	$\mathbf{F_1}$	$\mathbf{F_2}$	$\boldsymbol{TF} = (\frac{\mathbf{F1 - F1*}}{\mathbf{F1*}} + \frac{\mathbf{F2 - F2*}}{\mathbf{F2*}})$	$\mathbf{F_1}$	$\mathbf{F_2}$	$\boldsymbol{TF} = (\frac{\mathbf{F1 - F1*}}{\mathbf{F1*}} + \frac{\mathbf{F2 - F2*}}{\mathbf{F2*}})$
1	8.7554 e^{+11}	2.988322 e^{+3}	0.292343	8.1443545 e^{+11}	2.61503 e^{+3}	0.299249
2	7.5086 e^{+11}	2.428872 e^{+3}	0.319295	7.937165 e^{+11}	1.23566 e^{+3}	0.284612
3	7.6473 e^{+11}	2.464602 e^{+3}	0.326223	7.887665 e^{+11}	1.18359 e^{+3}	0.257143
4	7.6788 e^{+11}	2.887922 e^{+3}	0.290781	7.698075 e^{+11}	1.97643 e^{+3}	0.246355
5	7.5778 e^{+11}	5.089592 e^{+3}	0.290541	7.760495 e^{+11}	1.08452 e^{+3}	0.242624
6	7.6243 e^{+11}	2.066272 e^{+3}	0.26426	7.856435 e^{+11}	1.16344 e^{+3}	0.239415
7	7.5584 e^{+11}	4.810272 e^{+3}	0.256723	7.818885 e^{+11}	1.14565 e^{+3}	0.200639
8	8.4559 e^{+11}	3.926812 e^{+3}	0.225139	8.915175 e^{+11}	1.24517 e^{+3}	0.195087
9	8.2333 e^{+11}	3.715522 e^{+3}	0.180747	8.861335 e^{+11}	1.17456 e^{+3}	0.194922
10	7.5381 e^{+11}	3.130762 e^{+3}	0.179429	7.785035 e^{+11}	1.15467 e^{+3}	0.190841
11	8.133 e^{+11}	3.58081 e^{+3}	0.169146	8.695745 e^{+11}	1.68713 e^{+3}	0.179713
12	8.3603 e^{+11}	3.86399 e^{+3}	0.167286	8.726365 e^{+11}	1.38764 e^{+3}	0.166666

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13	7.7975 e^{+11}	2.90562 e^{+3}	0.166301	7.750315 e^{+11}	1.96144 e^{+3}	0.150709
14	8.1054 e^{+11}	3.55922 e^{+3}	0.149108	8.738895 e^{+11}	1.87312 e^{+3}	0.142651
15	8.0068 e^{+11}	3.49642 e^{+3}	0.143527	8.731535 e^{+11}	1.11469 e^{+3}	0.138164
16	8.7551 e^{+11}	3.75152 e^{+3}	0.131375	7.925185 e^{+11}	1.28764 e^{+3}	0.131326
17	7.5087 e^{+11}	2.90592 e^{+3}	0.120331	7.695655 e^{+11}	1.42986 e^{+3}	0.119959
18	7.6474 e^{+11}	3.20232 e^{+3}	0.119828	7.678915 e^{+11}	1.48653 e^{+3}	0.118043
19	7.6788 e^{+11}	3.73362 e^{+3}	0.116575	8.814895 e^{+11}	1.15667 e^{+3}	0.10943
20	7.5778 e^{+11}	3.31232 e^{+3}	0.110334	8.509765 e^{+11}	1.15677 e^{+3}	0.086381

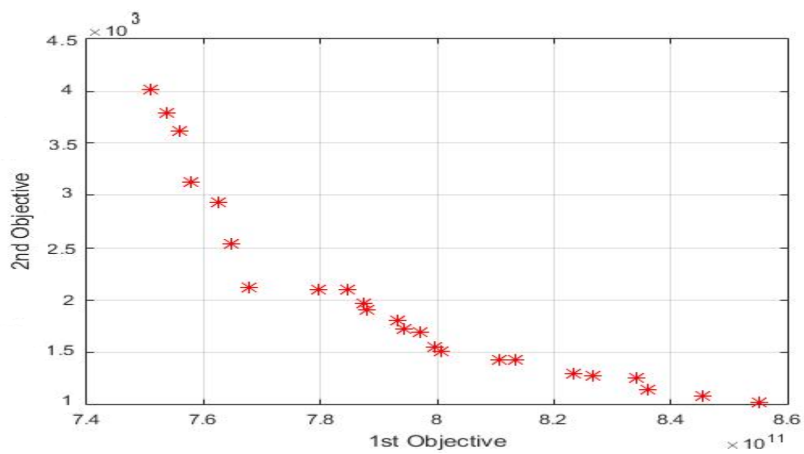

Figure 6. Solving by the NSGA II method

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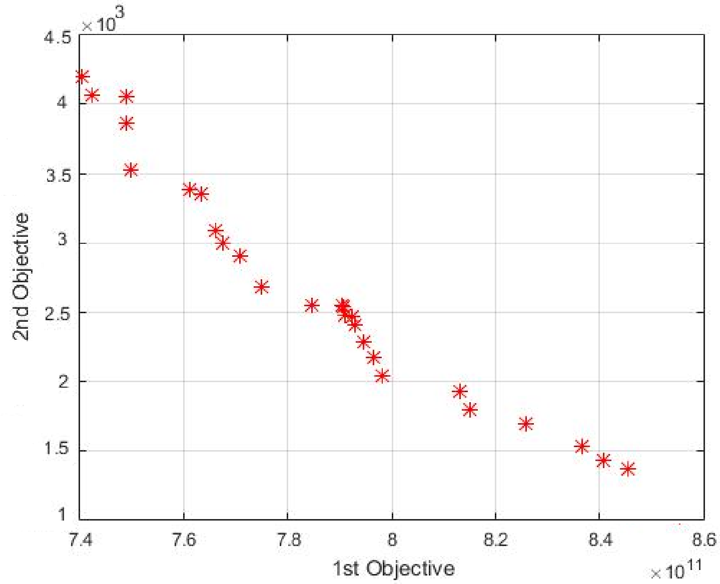

Figure 7. Solve by MOPSO method

Table 10. Total answers for vans

NO.	Parameters	Best Cost	Optimal sequence	Time
1	MaxIt = 100	7.7323E+11	best solution = 8 4 10 5 7 12 11 1 9 6 3 2	Time = 5.2225
2	MaxIt = 150	7.8928E+11	best solution = 8 4 10 5 7 12 11 1 9 6 3 2	Time = 7.3829
3	MaxIt = 200	8.02431E+11	best solution = 8 4 10 5 7 12 11 1 9 6 3 2	Time = 10.174

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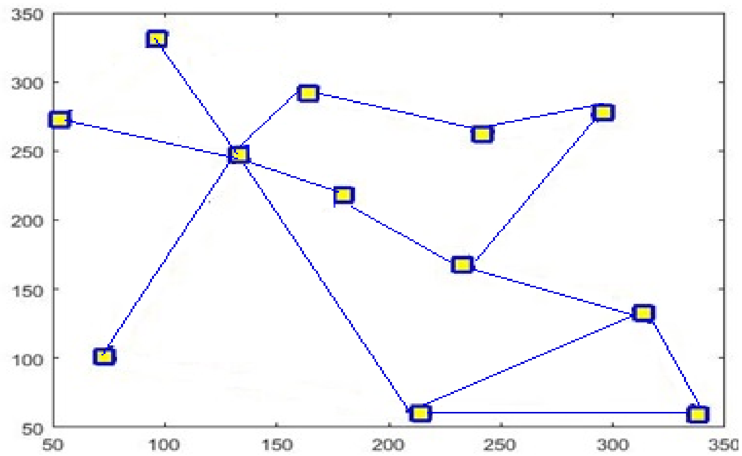

Figure 8. Points earned

Now considering the first two functions as TF function, we examine this function with F3 function. Results obtained when the functions are executed in the algorithm until the stop command is reached:

Table 11. algorithms until the stop command

N0.	NSGA II		MOPSO	
	F_3	TF	F_3	TF
1	$2.52e^{+12}$	$8.08e^{+12}$	$2.65e^{+12}$	$7.0e^{+12}$
2	$2.72e^{+12}$	$1.06e^{+12}$	$2.96e^{+12}$	$4.75e^{+12}$
3	$2.64e^{+12}$	$3.80e^{+12}$	$2.93e^{+12}$	$9.62e^{+12}$
4	$2.53e^{+12}$	$5.96e^{+12}$	$2.75e^{+12}$	$3.14e^{+12}$
5	$2.58e^{+12}$	$2.99e^{+12}$	$2.70e^{+12}$	$3.96e^{+12}$
6	$2.60e^{+12}$	$2.28e^{+12}$	$2.83e^{+12}$	$1.02e^{+13}$
7	$2.55e^{+12}$	$5.03e^{+12}$	$2.66e^{+12}$	$6.43e^{+12}$
8	$2.62e^{+12}$	$1.73e^{+12}$	$2.83e^{+12}$	$2.03e^{+12}$
9	$2.56e^{+12}$	$3.97e^{+12}$	$2.69e^{+12}$	$5.79e^{+12}$
10	$2.56e^{+12}$	$3.46e^{+12}$	$2.70e^{+12}$	$5.02e^{+12}$
11	$2.59e^{+12}$	$2.34e^{+12}$	$2.80e^{+12}$	$2.58e^{+12}$
12	$2.64e^{+12}$	$1.06e^{+12}$	$2.79e^{+12}$	$2.75e^{+12}$
13	$2.62e^{+12}$	$1.23e^{+12}$	$2.70e^{+12}$	$5.51e^{+12}$

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14	$2.55e^{+12}$	$5.48e^{+12}$	$2.65e^{+12}$	$7.00e^{+12}$
15	$2.54e^{+12}$	$5.85e^{+12}$	$2.96e^{+12}$	$4.75e^{+12}$
16	$2.52e^{+12}$	$8.08e^{+12}$	$2.93e^{+12}$	$9.62e^{+12}$
17	$2.72e^{+12}$	$1.06e^{+12}$	$2.75e^{+12}$	$3.14e^{+12}$
18	$2.64e^{+12}$	$3.80e^{+12}$	$2.70e^{+12}$	$3.96e^{+12}$
19	$2.53e^{+12}$	$5.96e^{+12}$	$2.83e^{+12}$	$9.75e^{+12}$
20	$2.58e^{+12}$	$2.99e^{+12}$	$2.66e^{+12}$	$6.43e^{+12}$

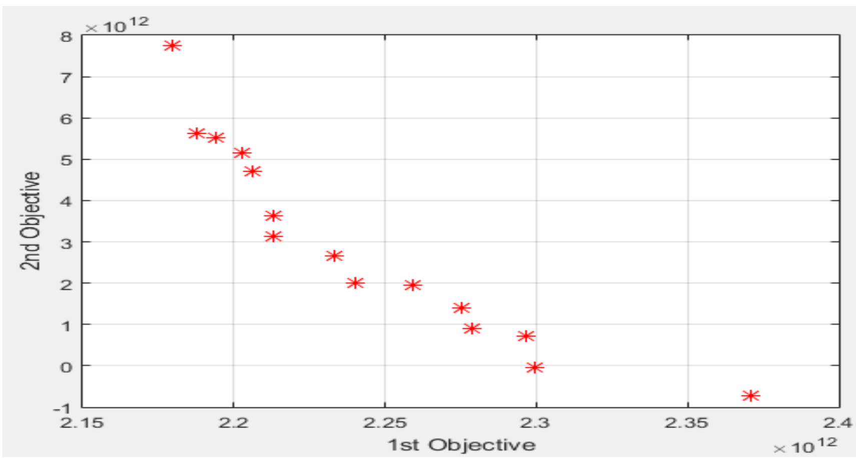

Figure 9. Solved by NSGA II method

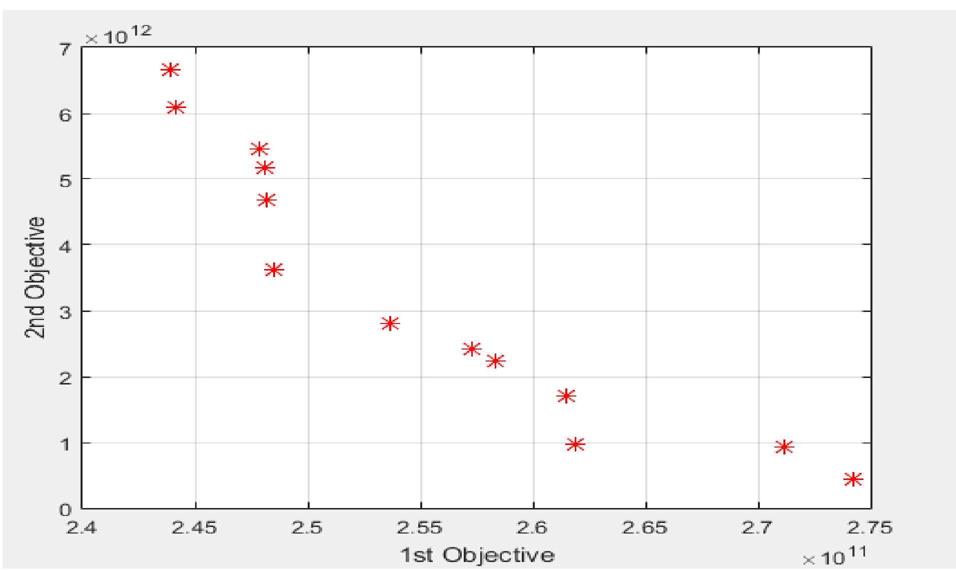

Figure 10. Solved by MOPSO method

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6. Discussion and Conclusion

The aim of the present study is to design a cold multi-cycle supply chain based on multi cross-docking taking into account uncertainty. In the first step, we identified the factors and variables of the model. In the second stage, by selecting the study period, through designing data collection forms and using the methods of reviewing the documents, the raw data required to measure the final indicators were collected and processed in the project model. Then, they were analyzed according to the research topic and using genetic algorithm and particle swarm optimization. This research uses genetic algorithm and particle swarm optimization for evaluation. As mentioned before, docking is one of the heuristic warehousing strategies in controlling distribution and logistics costs and maintaining the level of customer service simultaneously. Cross-docking of shipments usually takes between one and 5 hours, so that the cross-docking not only provides customers with goods but also offers many advantages over traditional warehousing, such as reduced inventory capital, smaller storage space, lower handling costs and shorter duty cycle time. In this problem, the incoming trucks, after loading the products from the suppliers, move directly toward the customers or toward another supplier, or move to one of the cross docks where the products are unloaded at the cross dock. Then, the products are loaded in the dispatching trucks and transported to the customers. Of note, a truck can load products from more than one supplier, and it can move toward more than one customer and unload products. Several trucks with different capacities can be used to transport products. In this study, the problem had two opposite objective functions. The primary objective function is to minimize the cost of transportation and warehousing throughout the supply chain, and the second aims to minimize the total time of operations within the supply chain and the number of vehicles. Obviously, simply saving on the cost function is in good condition, regardless of the product delivery time. Then, using simulated examples, it is shown that the L1 metric method can make a good correspondence between cost and time objective function. In the next step, meta-heuristic optimization methods (strongly adjustable) were used to deal with the travel time of suburban vehicles. In this study, we also provided an example of the performance of optimization models (weighted sum method and goal programing) for a small-sized sample. The computational results showed that costs will not necesarrily increase with longer the travel time and distance, rather it is possible to distribute the products with the right number of trucks at an optimal cost at the right time. We have also shown that the cost objective function value has not deteriorated in models with longer time. The results also show that waste can be reduced by choosing the right path.

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