Journal of Industrial and Systems Engineering
Vol. 15, No. 3, pp. 145-159
Summer (July) 2023

Meta-heuristic algorithms in solving the perishable supply chain network problem considering the queuing system based on robust possibilistic programming

Ramona Mojarrad langroudi[1*] AmirParsa Ahadi[2], Amin Saeidi khasraghi[3], Mohammad Reza Nasiri Janagha[4]

[1]Department of Industrial Management, North Tehran Branch, Islamic Azad University, Tehran, Iran,
[2]Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran
[3]Department of Industrial Engineering, University of Eyvanekey, Eyvanekey, Iran

[4]Department of Industrial Engineering, Lahijan Branch, Islamic Azad University, Lahijan, Iran,

Abstract

In a real world, there are some products and goods such as meat, vegetables, fruits and flowers that decay during the time. The producer has to produce more than the market demand due to the decay of some of the perishable goods. The perishable goods affect the production planning, goods preservation policy and the retailer's decision making. The retailer should also consider the good's perishability in her/his decision making. Therefore, one of the attractive and considerable subcategories of the supply chain management is the appropriate design of the chain network in supplying the perishable goods in which the main challenge is decreasing the expenses of production and preservation and also the perishable goods is one of the challenges of the perishable goods. In this article, a model of supply chain for perishable goods has been considered which is used to control the uncertain parameters by robust possibilistic programming and the meta-heuristic algorithms such as PSO, ALO and GWO are used to solve it. The results show that the GWO algorithm is much more efficient than other algorithms. To compare these algorithms, the means of total cost and CPU-time have been used. Also, T-test was

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[*] Corresponding author

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used to study the significant index means derived from the meta-heuristic algorithms which shows no significant difference between the objective function and the CPU-time.

Keywords: Perishable Supply Chain; Robust Possibilistic Programming; Queue System

1. Introduction

Many researchers of food supply chain have concentrated on the importance of this issue in the field of managing the supply chain in recent years (Biza et al., 2024, Fallah & Nozari, 2021). one of the concerns of the companies involved in the supply chain is supplying the healthy food with a high quality particularly the ones that have more specific conditions such as perishable foods (Yousefi-Banadi et al., 2017; Chobar et al. 2022). The dangers of the food could appear at any stage of the food supply chain and makes it necessary to determine the critical control points to get information about the food, production, expiration date and etc. Also, presenting it in a clear way for the participants and the consumers of the supply chain in food supply chain due to the specific conditions of the chain such as climate, seasonality of raw materials, decay at a specific time, and the specific preservation conditions makes it more unreliable (Abbas et al., 2023). Considering the researches, the food industry supply chain is constantly changing. The change in the food preferences, shopping habits and life styles puts more pressure on fast preparation of food. On the other hand, demographic progress has made more demands for fresh produces and the foods with a higher added value (Kovačić et al., 2015). Likewise, considering the existing product's variety in the market, the challenge of prediction and response to the customer demand becomes more important for the producers and retailers. Besides, producers and retailers should have more concentration on managing the delivery time in order to get the customer's satisfaction (De Keizer et al., 2017, Movahed et al., 2023). Therefore, since the subject of food supply chain is of importance and there are some challenges in this field such as changes in the customer's demand, delivery time, inventory shortage and etc. In addition, because the perishable foods have a more specific conditions than the non-perishable foods, managing the food supply chain becomes more essential in that if the products are not delivered on time and decay during the cycle, the total supply chain will undergo a huge cost (Tirkolaee & Aydin, 2022; Ashoka & Keihani, 2020). The operating model of the supply chain is considered a strong means which can be effective in understanding and studying the effect of supply chain on the function variable, how to manage the determining tactical factors and their relations. Therefore, an operating model of the supply chain consists of two essential decisions; tactical and strategic. The strategic decisions are related to the organization's long-term decisions and range from one to some years of time. Generally, these decisions include deciding on the number and the place of facilities (location), the situation and capacity of the storeroom, and the food's flow in the supply chain network (Diabat et al., 2019; Sadeghi et al. 2023, Lotfi et al., 2016, Aliahmadi et al., 2016). On the contrary, the tactical decisions are relevant to the organization's mid-term decisions and range from a couple of months to one year. These decisions include purchase and production, coordination of production and distribution, inventory policy, transportation strategy and discount (Pan et al., 2023; Salahi et al. 2023, Nozari et al., 2016, Bathaee et al., 2023). At the strategic level, the decisions relevant to the body of supply chain network including the place and number of facilities are made and at the tactical level, supposing the body of the supply chain network has already been done, optimizing the production amounts, inventory, coordinating production and distribution, determining the price level and etc. are performed (Zahiri et al., 2018; Cao et al. 2022). Given that establishing, opening and closing the facilities is a time-consuming and expensive process, it is not possible and logical to change them in a short time once the long-term decisions have been made. On the other hand, the tactical and operating decisions are determined after the strategic decisions; therefore, the body of the supply chain network is a limitation for the decisions at operating and tactical levels.

Uncertain parameters are usually considered in designing the supply chain model; given the important parameters of the supply chain, including demand could have a significant influence on the tactical and strategic decisions of the problem. Hence, a useful tool must be used to estimate and control the uncertain parameters (Fahmy et al., 2023; Mehrani et al. 2019, Fallah et al., 2021). Considering the mentioned points, the integration of the main strategic and tactical decisions in a supply chain network could both make cohesion among different decision-making in the supply chain network and save money long-term or increase benefits of the supply chain network. One of the other issues to be studied in the supply chain network is to reduce the customer waiting time in queue. Therefore, there should be an appropriate management on the inventory of the perishable products in the storerooms in order not to spend much time in queues for the customers. Overall, in case the inventory of the storeroom increases, the queue length decreases and so does the customer's waiting, whereas this will increase the network's expenses and respectively the profits will come down. Hence, the important issue of Jackson networks should be considered in designing the supply chain network problem.

2. Literature Review

PariAzar et al. (2017) presented a model of a two-step random schedule to decrease the expenses and also to decrease the risk in a food and drug supply network chain. The first decisions included strategic decisions like determining the number of the suppliers considering their place and capacity. However, the second decision was related to the transportation operations. Dai et al. (2018) integrated a location-inventory problem into a supply chain network and developed an optimization model for perishable products with fuzzy capacity and carbon emissions constraints. This model is formulated a mixed integer nonlinear programming model. Diabat et al. (2019) made a model of the perishable goods supply chain network by considering reliability and disorder. They took two purposes into account in this model; reducing the time of delivery of the perishable goods to the customers and reducing the expenses of the whole network. They also used the epsilon limitation method to solve the model. Amiri et al. (2020) represented a model to determine the optimal sales level of perishable products in a two-echelon supply chain, using a Vendor Managed Inventory (VMI) policy. The proposed model is formulated based on one vendor and multiple buyers. Considering buyers' requests in various periods, this model aims to optimize the sales profit by exact and meta-heuristics methods. Biuki et al. (2020) introduced a model of integrated location, routing, and inventory problem, the three key problems in optimizing a logistics system. Since finding the optimal solution for this problem is a NP-hard problem, two hybrid metaheuristics as parallel and series combinations of GA and PSO are utilized to solve the problem. Nasrollahi and Razmi (2021) presented a mathematical model for the homogenous pharmaceutical supply chain as well as the maximum regional coverage under uncertainties in an article. Their main purpose in the article was to increase the maximum customer demands beside a decrease in the total network expenses. They used Centroid method to control their own uncertain parameters. Jouzdani and Govindan (2021) designed a sustainable perishable food supply chain network. In this study, product lifetime uncertainty is explicitly modeled as a Weibull random variable, and food perishability is assumed to be affected by vehicle refrigerator utilization, which is considered as a decision variable. Foroozesh et al. (2022) designed a novel perishable supply chain network under uncertainty. This study aims to minimize effects of the disruption by presenting new strategies, such as multiple sourcing, financial suppliers, horizontal collaboration, route risk, and coverage radius, in designing a new multi-objective mixed-integer linear programming model for multi-product, multi-period, multi-modal G-Resilient supply chain. Pan et al. (2023) developed a nonlinear mixed integer programming model for the multi-echelon, multi-product, and multi-period location-inventory-routing problem (LIRP) in the PPSCN. Two hybrid metaheuristic algorithms, namely genetic algorithm (GA) and multiple population genetic algorithm (MPGA), are hybridized with variable neighborhood search (VNS) and proposed to solve this NP-hard problem. Biza et al. (2024) proposed a mathematical model (multi echelon, multi product, and multi period) for designing a perishable product supply chain network, considering factors like perishability, quantity discount policy, souring strategies and business continuity. The study explores the impact of these factors on the Agri Fresh Food Supply Chain design and its overall performances.

By studying the review of the literature, we find out that there are several articles which discuss the modeling of the perishable supply chain networks. In most of these articles, the tactical and strategic decisions have constantly been studied and the main focus is on optimizing the flow amount among the supply chain members. Also, no article discusses the review of queuing systems in the perishable supply chain network. At the end there are few articles studying and modeling the decision on location and network inventory for the perishable goods. By studying these articles, we realize that there is no comprehensive decision-making model for location-allocation and the inventory in the uncertain conditions of demand to reduce the customer waiting time by considering queue system. Therefore, there is the robust possibilistic programming to control a perishable supply chain network by considering the queuing system. To make the issue look more real, demand, transportation costs and the capacity of the distribution centers are considered uncertainly.

3. Problem Definition

In this article, the modeling of a perishable supply chain network considering the queuing system, including suppliers, production centers, distribution centers and customers has been discussed. According to ***Figure (1)***, the suppliers send the raw materials needed for the production of products to the production centers by observing the perishability time. Production centers also produce and send products to distribution centers based on uncertain customer demand. Distribution centers distribute products according to customer demand using different vehicles. Due to the perishability of products in this issue, some products can be stored in production and distribution centers. On the other hand, the distribution of products from the distribution center to customers is based on a queue system. In this queuing system, the products that can be supplied to customers are planned based on the arrival rate and the service rate, and there is the possibility of creating a queue and delay in sending the products. Various strategic and tactical decisions are simultaneously considered in this mathematical model, which can be mentioned in inventory management in production and distribution centers, management of product transfer flow between the supply chain and reducing the length of product distribution queues in the distribution center. The main objective function of the problem is to minimize the total costs of the perishable supply chain network considering the queuing system.

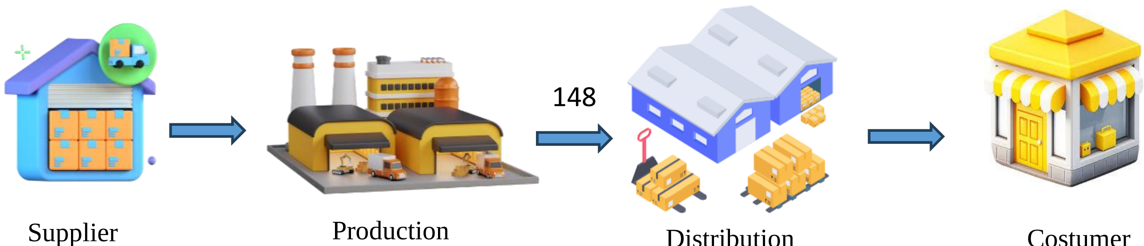

Figure1. Uncertain perishable supply chain network

To model the perishable supply chain problem considering the queuing system, the following assumptions are considered:

- The optimal number of facilities such as suppliers, production centers and distribution centers are unknown.
- The amount of demand, the cost of transportation and the capacity of distribution centers are uncertain.
- The capacity of heterogeneous vehicles is known.
- The mathematical model is multi-period and multi-product.
- The service rate is known in the distribution centers.
- The arrival rate is based on the Poisson distribution function and the service rate is based on the exponential distribution function.
- Queuing system type $M/M/m/C$ consists of m servers with capacity

Based on the above assumptions, the definitions of the symbols used in the mathematical model as well as the modeling of the problem have been discussed.

Sets

I	Potential $i = \{1, \dots, I\}$
J	Potential $j = \{1, \dots, J\}$
K	Potential $k = \{1, \dots, K\}$
H	Customer $h = \{1, \dots, H\}$
P	Product $p = \{1, \dots, P\}$
T	Period $t = \{1, \dots, T\}$؛ Production time $r = \{1, \dots, T\}$ ؛Delivery time $e = \{1, \dots, T\}$
V	Vehicle $v = \{1, \dots, V\}$

Parameters

Ci_i	cost of selecting supplier $i \in I$
Cj_j	cost of producer center set up $j \in J$
Ck_k	cost of distribution center set up $k \in K$
$\widetilde{Trij}_{ijpv}$	Transportation cost of product $p \in P$, between the supplier center $i \in I$, and production center $j \in J$ by vehicle $v \in V$
$\widetilde{Trjk}_{jkpv}$	Transportation cost of product $p \in P$, between the production center $j \in J$ and the distribution center $k \in K$ by vehicle $v \in V$
$\widetilde{Trkh}_{khpv}$	Transportation cost of product $p \in P$, between the distribution center $k \in K$ and the customer $h \in H$ by vehicle $v \in V$
Hj_{jp}	Inventory cost of product $p \in P$ in the production center $j \in J$
Hk_{kp}	Inventory cost of product $p \in P$ in the distribution center $k \in K$
$\widetilde{Dem}_{hpt}$	Demand of product $p \in P$ for customer $h \in H$ at period $t \in T$
u_p	Perishable time for product $p \in P$
$CapI_{ip}$	capacity of product $p \in P$ for supplier $i \in I$
$CapJ_{jp}$	capacity of product $p \in P$ for production center $j \in J$

$\widetilde{CapK}_{kp}$	capacity of product $p \in P$ for distribution center $k \in K$
ϑ_{kt}	The number of the servers in the distribution center $k \in K$
CT_k	Cost of waiting time to serve in the distribution center $k \in K$
μ_k	Rate of service in the distribution center $k \in K$
B_k	the maximum queue length for the service in the distribution center $k \in K$
θ_k	the possibility of the extreme queue length of the service in the distribution center $k \in K$

Decision variables

Xij_{ijpvt}	Amount of the product $p \in P$ transferred between the supplier $i \in I$ and the production center $j \in J$ at period $t \in T$ by vehicle $v \in V$
Xjk_{jkpvt}	Amount of the product $p \in P$ transferred between the production center $j \in J$ and the distribution center $k \in K$ at period $t \in T$ by vehicle $v \in V$
Xkh_{khpvt}	Amount of the product $p \in P$ transferred between the distribution center $k \in K$ and the customer $h \in H$ at period $t \in T$ by vehicle $v \in V$
T_{jkpvtr}	Amount of the product $p \in P$ transferred between the production center $j \in J$ and the distribution center $k \in K$ at period $t \in T$ and produced at time $r \in R$ by vehicle $v \in V$
$B_{khpvtre}$	Amount of the product $p \in P$ transferred between the distribution center $k \in K$ and the customer $h \in H$ at period $t \in T$ and produced at time $r \in R$ and received at time $e \in E$ by vehicle $v \in V$
Ij_{jptr}	Inventory level of product $p \in P$ in production center $j \in J$ at period $t \in T$ and produced at time $r \in R$
Ik_{kptre}	Inventory level of product $p \in P$ in distribution center $k \in K$ at period $t \in T$ and produced at time $r \in R$ and received at time $e \in E$
Yi_i	1; if supplier $i \in I$ is selected, 0; otherwise.
Yj_j	1; if production center $j \in J$ has been set up, 0; otherwise.
Yk_k	1; if distribution center $k \in K$ has been set up, 0; otherwise.
λ_{kt}	The rate of the customer's arrival to the distribution center $k \in K$ at period $t \in T$
π_{0kt}	The possibility of the establishing event at the distribution center $k \in K$ at period $t \in T$
W_{kt}	the customer's waiting time at the distribution center $k \in K$ at period $t \in T$

Considering the mentioned sets, parameters and the decision variables, the problem of perishable supply chain network is modeled as a non-linear mixed integer programming mathematical model is modeled as below:

$$\begin{aligned}\text{Min}\, Cost = {} & \sum_{i=1}^{I} Ci_i Yi_i + \sum_{j=1}^{J} Cj_j Yj_j + \sum_{k=1}^{K} Ck_k Yk_k + \sum_{k=1}^{K}\sum_{t=1}^{T} CT_k W_{kt} + \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r=1}^{t} Hj_{jp} Ij_{jptr} \\ & + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{e=r}^{t}\sum_{r=1}^{t} Hk_{kp} Ik_{kptre} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trij_{ijpv} Xij_{ijpvt} + \\ & \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trjk_{jkpv} Xjk_{jkpvt} + \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trkh_{khpv} Xkh_{khpvt}\end{aligned} \tag{1}$$

$s.t.$:

$$\sum_{r=1}^{t} Ij_{jptr} = \sum_{i=1}^{I}\sum_{v=1}^{V} Xij_{ijpvt} - \sum_{k=1}^{K}\sum_{v=1}^{V} Xjk_{jkpvt}\,, \qquad \forall j,p,t = 1 < u_p \tag{2}$$

$$\sum_{r=1}^{t} Ij_{jptr} = \sum_{r=1}^{t-1} Ij_{jpt-1r} + \sum_{i=1}^{I}\sum_{v=1}^{V} Xij_{ijpvt} - \sum_{k=1}^{K}\sum_{v=1}^{V} Xjk_{jkpvt}\,, \qquad \forall j,p,1 < t < u_p \tag{3}$$

$$\sum_{r=t+1-u_p}^{t} Ij_{jptr} = \sum_{r=t+1-u_p}^{t-1} Ij_{jpt-1r} + \sum_{i=1}^{I}\sum_{v=1}^{V} Xij_{ijpvt} - \sum_{k=1}^{K}\sum_{v=1}^{V} Xjk_{jkpvt}\,, \qquad \forall j,p,t \geq u_p \tag{4}$$

$$\sum_{v=1}^{V} Xjk_{jkpvt} = \sum_{r=1}^{t}\sum_{v=1}^{V} T_{jkpvtr}\,, \qquad \forall j,k,p,t < u_p \tag{5}$$

$$\sum_{v=1}^{V} Xjk_{jkpvt} = \sum_{r=t+1-u_p}^{t} \sum_{v=1}^{V} T_{jkpvtr}\,, \qquad \forall j,k,p,t \geq u_p \tag{6}$$

$$Ij_{jptr} = \sum_{i=1}^{I} \sum_{v=1}^{V} Xij_{ijpvt} - \sum_{k=1}^{K} \sum_{v=1}^{V} T_{jkpvtr}\,, \qquad \forall j,p,t = r \tag{7}$$

$$Ij_{jptr} = Ij_{jpt-1r} - \sum_{k=1}^{K} \sum_{v=1}^{V} T_{jkpvtr}\,, \qquad \forall j,p,t-r < u_p \tag{8}$$

$$\sum_{e=r}^{t} \sum_{r=1}^{t} Ik_{kptre} = \sum_{k=1}^{K} \sum_{v=1}^{V} Xjk_{jkpvt} - \sum_{h=1}^{H} \sum_{v=1}^{V} Xkh_{khpvt}\,, \qquad \forall l,p,t = 1 < u_p \tag{9}$$

$$\sum_{e=r}^{t} \sum_{r=1}^{t} Ik_{kptre} = \sum_{e=r}^{t-1} \sum_{r=1}^{t-1} Ik_{kpt-1re} + \sum_{k=1}^{K} \sum_{v=1}^{V} Xjk_{jkpvt} - \sum_{h=1}^{H} \sum_{v=1}^{V} Xkh_{khpvt}\,, \qquad \forall k,p,1 < t < u_p \tag{10}$$

$$\sum_{e=r}^{t+u_p-1} \sum_{r=t-u_p+1}^{t} Ik_{kptre} = \sum_{e=r}^{t-1} \sum_{r=t-u_p+1}^{t-1} Ik_{kpt-1re} + \sum_{k=1}^{K} \sum_{v=1}^{V} Xjk_{jkpvt} - \sum_{h=1}^{H} \sum_{v=1}^{V} Xkh_{khpvt}\,, \quad \forall k,p,t \geq u_p \tag{11}$$

$$\sum_{v=1}^{V} Xkh_{khpvt} = \sum_{e=r}^{t} \sum_{r=1}^{t} \sum_{v=1}^{V} B_{khpvtre}\,, \qquad \forall k,h,p,t < u_p \tag{12}$$

$$\sum_{v=1}^{V} Xkh_{khpvt} = \sum_{e=r}^{r+u_p-1} \sum_{r=t-u_p+1}^{t} \sum_{v=1}^{V} B_{khpvtre}\,, \qquad \forall k,h,p,t \geq u_p \tag{13}$$

$$Ik_{kptre} = \sum_{j=1}^{J} \sum_{v=1}^{V} T_{jkpvtr} - \sum_{h=1}^{H} \sum_{v=1}^{V} B_{khpvtre}\,, \qquad \forall k,p,r,t = e \tag{14}$$

$$Ik_{kptre} = Ik_{kpt-1re} - \sum_{h=1}^{H} \sum_{v=1}^{V} B_{khpvtre}\,, \qquad \forall k,p,r,t-e < u_p \tag{15}$$

$$\sum_{k=1}^{K} \sum_{v=1}^{V} Xkh_{khpvt} \geq Dem_{hpt}, \qquad \forall h,p,t \tag{16}$$

$$\sum_{j=1}^{J} \sum_{v=1}^{V} Xij_{ijpvt} \leq CapI_{ip} Yi_i, \qquad \forall i,p,t \tag{17}$$

$$\sum_{i=1}^{I} \sum_{v=1}^{V} Xjk_{jkpvt} \leq CapJ_{jp} Yj_j, \qquad \forall j,p,t \tag{18}$$

$$\sum_{j=1}^{J} \sum_{v=1}^{V} Xkh_{khpvt} \leq CapK_{kp} Yk_k, \qquad \forall k,p,t \tag{19}$$

$$\lambda_{kt} = \sum_{p=1}^{P} \sum_{j=1}^{I} \sum_{v=1}^{V} X_{jkpvt}\,, \qquad \forall k,t \tag{20}$$

$$\pi_{0kt} = \left[\sum_{k'=0}^{\vartheta_k - 1} \frac{1}{k'!} \left(\frac{\lambda_{kt}}{\mu_k} \right)^{k'} + \frac{1}{\vartheta_k!} \left(\frac{\lambda_{kt}}{\mu_k} \right)^{\vartheta_k} \left(\frac{\vartheta_k \mu_k}{\vartheta_k \mu_k - \lambda_{kt}} \right) \right]^{-1}, \qquad \forall k,t \tag{21}$$

$$P_{k'kt} = \left(\sum_{k'=0}^{\vartheta_k} \frac{\lambda_{kt}^{k'}}{k'!\, \mu_k^{k'}} + \sum_{k'=\vartheta_k+1}^{\vartheta_k + B_k} \frac{\lambda_{kt}^{k'} {\vartheta_k}^{k' - \vartheta_k}}{k'!\, \mu_k^{k'}} \right) \pi_{0kt} \geq 1 - \theta_k, \qquad \forall k,t \tag{22}$$

$$W_{kt} = \left[\frac{\pi_{0kt}}{\vartheta_k!} \left(\frac{\lambda_{kt}}{\mu_k} \right)^{\vartheta_k!} \frac{\vartheta_k \mu_k}{(\vartheta_k \mu_k - \lambda_{kt})^2} + \frac{1}{\mu_k} \right] Yk_k, \qquad \forall k,t \tag{23}$$

$$Ij_{jptr} = 0 \quad \forall j,p,t < r \tag{24}$$

$$Ik_{kptr} = 0 \quad \forall l,p,e,t < r \tag{25}$$

$$Ik_{kptr} = 0 \quad \forall l,p,t,e < r \tag{26}$$

$$Xij_{ijpvt}, Xjk_{jkpvt}, Xkh_{klhpt}, B_{khpvtre}, T_{jkpvtr} \geq 0 \,\&\, integer \quad \forall i,j,k,ch,p,v,t,r,e \tag{27}$$

$$Yi_i, Yj_j, Yk_k, Rij_{ijvt}, Rjk_{jkvt}, Rkh_{khvt} \in \{0,1\} \quad \forall i,j,k,k,v,t \tag{28}$$

Equation (1) shows the costs of the total supply chain network, including facility location costs, inventory costs, and transportation costs. Constraints (2) to (4) show the inventory level of products considering the time of perishability in different periods in the production center. Constraints (5) and (6) show the total flow of a type of perishable product from the producer to the distribution center at the time of production of the products. Constraints (7) and (8) show the inventory level of finished products for a distribution center based on the production time of the products. Constraints (9) to (11) show the inventory level of final products in different time periods in distribution centers. Constraints (12) to (15) examine the output of perishable products based on the production time of the products. Constraint (16) guarantees that the total customer demand of each product is satisfied in each time period. Constraints (17) to (19) show the maximum use of supplier capacity, production and distribution centers. Constraints (20) shows the input rate corresponding to the supply chain model of perishable goods. Constraint (21) shows the probability of the selection of the node as the distribution center $k \in K$ in the time period $t \in T$. Constraint (22) shows the probability of steady state for the presence of n customers in the service queue of distribution center $k \in K$. Constraint (23) calculates the customer's waiting time in distribution center $k \in K$. Constraints (24) to (26) show the logical constraints related to the inventory of warehouses in production and distribution centers. Finally, the constraints (27) and (28) show the gender and type of decision-making variables.

Due to the fluctuating and dynamic nature of some of the main parameters (including demand, transportation costs and distribution center capacity) which require a super-schedule and also due to the inaccessible and far-reached historical required data at the design stage, these parameters are mostly estimated relying on the experts' viewpoints and mental experiences. Hence, the complex parameters above are formulated as the uncertain data in the format of trapezoidal fuzzy numbers as the following:

$$\widetilde{Dem}_{hpt} = (Dem^1_{hpt}, Dem^2_{hpt}, Dem^3_{hpt}, Dem^4_{hpt})$$

$$\widetilde{Trij}_{ijpv} = (Trij^1_{ijpv}, Trij^2_{ijpv}, Trij^3_{ijpv}, Trij^4_{ijpv})$$

$$\widetilde{Trjk}_{jkpv} = (Trjk^1_{jkpv}, Trjk^2_{jkpv}, Trjk^3_{jkpv}, Trjk^4_{jkpv})$$

$$\widetilde{Trkh}_{khpv} = (Trkh^1_{khpv}, Trkh^2_{khpv}, Trkh^3_{khpv}, Trkh^4_{khpv})$$

$$\widetilde{CapK}_{kp} = (CapK^1_{kp}, CapK^2_{kp}, CapK^3_{kp}, CapK^4_{kp})$$

It is worth mentioning that it is hard and sometimes impossible to have certain demand assessment for the long-term decisions. Even if one could estimate a possible distribution function for these two parameters, it would be likely that these parameters do not have the same behaviors with the prior data. Therefore, the demand for any product at any period, the cost of transporting the perishable goods between the facilities and the capacity of the distribution center which change in a long-term schedule, are considered as the fuzzy data.

In this article, the uncertain robust schedule is applied into the presented model which is described as the following:

$$\begin{aligned}
&Min\ Cost = E[cost] + \xi\left(cost_{(\max)} - E[cost]\right) + \\
&\eta_1\left(d^4 - d^3 - \alpha(d^4 - d^3)\right) + \eta_2 y\left[\left(S^2 - S^1 - \beta(S^2 - S^1)\right)\right] \\
&s.t.: \\
&Ax \geq (1-\alpha)d^3 + \alpha d^4 \\
&Bx \leq [(1-\beta)S^2 + \beta S^1]y \\
&y, \in \{0,1\}, \quad x \geq 0, \quad \alpha, \beta \in [0,1]
\end{aligned} \tag{29}$$

in which M is a large positive number, and the vectors d and S represent the demand and capacity. Also, A and B are the coefficient matrixes, and eventually x and y are constant and binary variables. Besides, α and β control the minimum assurance for the uncertain limitation with the pessimistic decision approach. Now, it is supposed that the vectors d and S in the model above, are presented as the uncertain parameters and $Cost_{(\max)}$ is expressed as the following:

$$Cost_{(max)} = Cy + F^4x \tag{30}$$

In the objective function of constraint (30), the first phrase points out the expected amount of the first target function by means of the average amounts of the uncertain parameters of the model. The second phrase points out the penalty price for the extra deviation from the expected amount of the objective function (robust optimization). The third phrase shows the total penalty for the deviation from the demand (uncertain parameter). Accordingly, the parameter ξ is the weight coefficient of the target function; η_1 is the penalty for not fulfilling the demand; η_2 is the function of penalty exceeding the distribution center capacity. The parameters α and β show the correction coefficient in the fuzzy levels of numbers which must be between 1 and 0. Therefore, the final model for the controlled perishable goods supply chain network is described as the following:

$$\begin{aligned} Min\, Z_1 = {} & E[Z_1] + \xi\left(Z_{1_{(\max)}} - E[Z_1]\right) + \eta_1 \sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{t=1}^{T}\left(Dem_{cpt}^4 - Dem_{cpt}^3 - \alpha\left(Dem_{cpt}^4 - Dem_{cpt}^3\right)\right) + \\ & \eta_2 \sum_{k=1}^{K}\sum_{p=1}^{P}\left(CapK_{kp}^2 - CapK_{kp}^1 - \beta\left(CapK_{kp}^2 - CapK_{kp}^1\right)\right)Yk_k \end{aligned} \tag{31}$$

$s.t.$:

$$\begin{aligned} E[Cost] = {} & \sum_{i=1}^{I} Ci_iYi_i + \sum_{j=1}^{J} Cj_jYj_j + \sum_{k=1}^{K} Ck_kYk_k + \sum_{k=1}^{K}\sum_{t=1}^{T} CT_kW_{kt} + \\ & \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r=1}^{t} Hj_{jp}Ij_{jptr} + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{e=r}^{t}\sum_{r=1}^{t} Hk_{kp}Ik_{kptre} \\ & + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V}\left(\frac{Trij_{ijpv}^1 + Trij_{ijpv}^2 + Trij_{ijpv}^3 + Trij_{ijpv}^4}{4}\right)Xij_{ijpvt} \\ & + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V}\left(\frac{Trjk_{jkpv}^1 + Trjk_{jkpv}^2 + Trjk_{jkpv}^3 + Trjk_{jkpv}^4}{4}\right)Xjk_{jkpvt} \\ & + \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V}\left(\frac{Trkh_{khpv}^1 + Trkh_{khpv}^2 + Trkh_{khpv}^3 + Trkh_{khpv}^4}{4}\right)Xkh_{khpvt} \end{aligned} \tag{32}$$

$$\begin{aligned} Cost_{(\max)} = {} & \sum_{i=1}^{I} Ci_iYi_i + \sum_{j=1}^{J} Cj_jYj_j + \sum_{k=1}^{K} Ck_kYk_k + \sum_{k=1}^{K}\sum_{t=1}^{T} CT_kW_{kt} + \\ & \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r=1}^{t} Hj_{jp}Ij_{jptr} + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{e=r}^{t}\sum_{r=1}^{t} Hk_{kp}Ik_{kptre} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trij_{ijpv}^4.Xij_{ijpvt} \\ & + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trjk_{jkpv}^4.Xjk_{jkpvt} + \sum_{k=1}^{K}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{v=1}^{V} Trkh_{khpv}^4.Xkh_{khpvt} \end{aligned} \tag{33}$$

$$\sum_{k=1}^{K}\sum_{v=1}^{V} Xkh_{khpvt} \geq \alpha Dem_{cpt}^4 + (1-\alpha)Dem_{cpt}^3, \qquad \forall h, p, t \tag{34}$$

$$\sum_{j=1}^{J}\sum_{v=1}^{V} Xkh_{khpvt} \leq \left[\beta CapK_{kp}^2 + (1-\beta)CapK_{kp}^1\right]Yk_k, \qquad \forall k, p, t \tag{35}$$

$$Eqs. (2\ \ldots\ 15)\ \&\ (17 \ldots 18)\ \&\ (20 \ldots 28) \tag{36}$$

4. Analysis of results

In this part, in order to validate the model and also to observe the model's output variables, a sample problem at a small size (three potential suppliers, four potential production centers, five potential distribution centers, five customers, two products in four time periods with three vehicles) as well as the certain and uncertain parameters in ***Table (1)*** was designed.

Table 1. Parameter intervals of the problem based on the uniform distribution function

Parameter	Parameter intervals	Parameter	Parameter intervals
Ci_i	$\sim U(30000{,}50000)$	$CapJ_{jp}$	$\sim U(50{,}80)$
Cj_j	$\sim U(30000{,}50000)$	ϑ_{kt}	3
Ck_k	$\sim U(10000{,}150000)$	CT_k	$\sim U(120{,}150)$
u_p	$\sim U(1{,}3)$	μ_k	$\sim U(200{,}220)$
$CapI_{ip}$	$\sim U(50{,}80)$	Hj_{jp}	$\sim U(1{,}5)$
Hk_{kp}	$\sim U(1{,}5)$		

Parameter	***parameter intervals***
$Trij_{ijpv}$	$\sim U\ [(15{,}20)\,,(20{,}25)\,,(25{,}30)\,,(30{,}45)]$
$Trjk_{jkpv}$	$\sim U\ [(15{,}20)\,,(20{,}25)\,,(25{,}30)\,,(30{,}45)]$
$Trkh_{khpv}$	$\sim U\ [(15{,}20)\,,(20{,}25)\,,(25{,}30)\,,(30{,}45)]$
Dem_{hpt}	$\sim U\ [(5{,}10)\,,(10{,}15)\,,(15{,}20)\,,(20{,}40)]$
$CapK_{kp}$	$\sim U\ [(30{,}50)\,,(50{,}80)\,,(80{,}100)\,,(100{,}120)]$

Since there is no access to the real-world input, and the model's developing nature, the data in ***Table (1)*** are considered as a uniform distribution function. Hence, the high and the low bounds of the problem are chosen regarding the expressed interval in the basic articles. To solve the first model there are some supposed conditions; to control the uncertain parameters, the uncertain rate amount of α and β are supposed as 0.5. Based on this, the total cost of the perishable supply chain network is $217115.89. As a result of this analysis, suppliers number 1 and 3, production centers 2 and 4, and distribution centers 3 and 5 have been selected from potential points.

In the following, the analysis of the problem's sensitivity of the designed supply chain network through the robust possibilistic programming is addressed. Therefore, the ***Figure (2)***, express the quantity changes of the problem's target functions for each various parameters α=β on the first studied efficient response in the previous part.

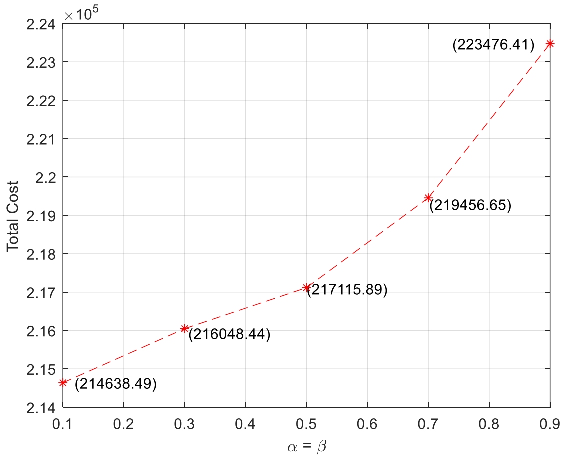

Figure 2. The changes of the quantity of the first target function for each robust fuzzy parameters

According to the obtained results from the analysis of the sensitivity, it is seen that by increasing the parameters α = β, due to the demand increase, transportation costs, and the number of the vehicles to deliver the goods have also increased. Therefore, when these factors increase, the quantity of the first and second functions increase as well. Due to the large number of the vehicles for delivering the goods, the transferring time for the goods from the origin to the destination (supplier to the customer) has increased which has made the third target function increase.

In the following, meta-heuristic algorithms such as (Gray Wolf Optimizer (GWO), Ant Lion Optimizer (ALO) and also Particle Swarm Optimization (PSO)) are used to solve the problem in large sizes. In the literature, these algorithms have been used by many researchers in solving supply chain problems. In order to evaluate and assess GWO, ALO and PSO algorithms, the small problem was solved with the mentioned algorithms. ***Table (2)*** shows the optimal parameters of GWO, ALO and PSO algorithms derived from Taguchi method, before the problem solution.

Table 2. Optimal parameters of PSO, GWO and ALO algorithms

PSO		GWO		ALO	
Parameter	Optimum	Parameter	Optimum	Parameter	Optimum
N particle	150	N gray wolf	150	N ant lion	150
Max it	200	Max it	200	Max it	200
C1	1.5	A	1	A	2
C2	2	C	1.5	C	1

After tuning the optimal parameters of meta-heuristic algorithms, in the following, the issue of solving the problem at a small size is discussed.

In this analysis, the value of the objective function obtained by PSO equals $217,235.41, by GWO equals $217,646.14, and by ALO equals $217,546.15. Based on the obtained values, the RPD value of the PSO algorithm is equal to 0.05, the GWO algorithm is equal to 0.24, and the ALO algorithm is equal to 0.19. This shows that the convergence of the proposed algorithms is very high in achieving a solution close to the optimum.

In the following, 30 sample problems at large sizes are designed based on the presented data in ***Table (1)***. Every sample problem designed at a large size by the PSO, ALO and GWO algorithms is performed 5 times and the means of the total indexes of each performance is shown in ***Table (3)***.

Table 3. The mean of the total costs obtained by meta-heuristics algorithm

	PSO		GWO		ALO	
Sample problem	Total Cost	CPU-time	Total Cost	CPU-time	Total Cost	CPU-time
1	292301.84	18.23	290258.06	11.23	297707.95	15.43
2	353723.80	54.00	355165.69	12.99	361541.86	37.59
3	380671.16	85.15	377628.41	16.88	384386.00	57.84
4	415633.04	121.27	413923.81	31.45	423236.12	85.34
5	603299.89	167.75	609620.71	43.45	617933.73	118.03
6	767500.08	217.20	768864.15	91.88	776325.77	167.07
7	821419.57	272.89	858071.38	118.71	868887.18	211.21
8	856441.12	334.54	865102.41	165.12	874199.26	266.77
9	880976.90	409.80	874958.26	241.44	883806.33	342.45
10	1026201.17	479.84	1071752.19	325.88	1083172.55	418.25
11	1173669.76	520.07	1230631.18	442.66	1237632.05	489.10
12	1524233.68	662.97	1540576.25	588.79	1550876.65	633.29

13	1729007.74	763.68	1707971.17	694.56	1718247.27	736.03
14	1800651.02	905.18	1797090.74	813.45	1804753.86	868.48
15	1829006.38	1138.17	1840793.86	984.45	1849768.61	1076.62
16	1862451.21	1347.64	1879511.67	1195.32	1887476.55	1286.71
17	1932586.23	1645.69	1942904.56	1395.36	1947688.13	1545.55
18	2015461.02	1964.82	2028230.25	1645.67	2035580.16	1837.16
19	2245986.32	2456.36	2256448.03	1920.03	2269967.85	2241.82
20	2458796.26	2884.55	2469767.58	2347.64	2486614.33	2669.78
21	2688746.24	3254.12	2706980.82	2864.69	2717932.07	3098.34
22	2947633.36	3823.36	2964581.65	3315.70	2968577.67	3620.29
23	3264764.36	4356.23	3277935.35	3894.37	3277536.85	4171.48
24	3662345.69	4914.85	3681847.91	4567.64	3675331.57	4775.96
25	3846625.23	5523.64	3856969.69	5213.68	3861775.40	5399.65
26	3969745.36	6233.23	3984132.80	6003.14	3996559.71	6141.19
27	4123386.25	6765.50	4137201.83	6945.22	4138471.89	6837.38
28	4265478.36	7528.02	4283133.53	7736.66	4291764.06	7611.47
29	4425743.36	8216.33	4443695.36	8647.07	4440613.86	8388.62
30	4658791.66	8964.15	4670660.39	9459.73	4687376.93	9162.38
Mean	2094109.27	2534.308	2106214.66	2391.162	2113858.07	2477.043

The results of ***Table (3)*** show that relatively, the PSO algorithm has obtained the lowest average total costs compared to other algorithms. While the speed of the algorithm to reach the optimal solution was higher by the GWO algorithm. In ***Table (4)***, the mean of the total cost and CPU-time for the meta-heuristic algorithms in each sample problem by PSO, ALO and GWO algorithms are shown. To compare the achieved results from the T-test at the 95% confidence interval was applied to compare the significant difference of the means for each index. Therefore, if the number of the P-value achieved from each index is less than 0.5, the null hypothesis is rejected and it shows there is a significant difference between the means of the indexes. If the P-value is over 0.95, hypothesis (1) is rejected which shows there is no significant difference between the mean of the indexes. ***Table (4)*** shows the results derived for the t-test on the target function mean and the comparison indexes.

Table 4. T-test results on the mean of the total cost and CPU-time

Algorithm	Estimate for difference	95% confidence interval	T-value	P-value
PSO-GWO	12104	(-705907, 30116)	0.03	0.973
ALO-GWO	7644	(-710694, 725983)	0.02	0.983
ALO-PSO	19749	(-697945, 737443)	0.06	0.956
PSO-GWO	143	(-1312, 1599)	0.20	0.845
ALO-GWO	86	(-1379, 1550)	0.12	0.907
ALO-PSO	57	(-1383, 1497)	0.08	0.937

According to ***Table (4)*** and the results derived from the P-value, there is no significant difference between the achieved objective function and the CPU-time of the meta-heuristic indexes. Therefore, other decision-making methods ought to be applied to choose the most efficient algorithm regarding the comparative indexes. In the following, ***Figure (3)*** shows the comparison between the Total cost and CPU-time regarding solving the sample problem by meta-heuristic algorithm.

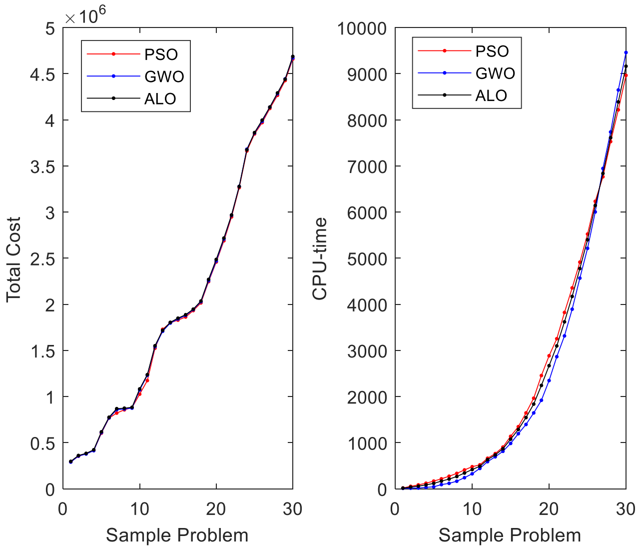

Figure 3. Comparison between total cost and CPU-Time in sample problems

By looking closely to ***Figure (3)***, it is achieved that the computational time increases when the sample problem size increases exponentially which is a good reason for the body problem to be NP-Hard. However, GWO and ALO algorithm is better than PSO in solving the moderate size problems regarding the computational time. Nevertheless, the computational time achieved by this algorithm increases dramatically when the problem's size increases.

5. Conclusion

This paper is about designing a multi-product multi-period perishable supply chain network with uncertain demand by considering queue system. By studying the literature review, it is understood that there is no comprehensive decision-making model for location-allocation-inventory problem under uncertain demand conditions, regarding Jackson's model to reduce the customer's cost waiting time. Therefore, the robust possibilistic programming was used for control the uncertainty parameter in perishable supply chain network. The main objective function of the paper was minimizing the total network cost as well as the customer's waiting time in queuing system. To get close to the real world, demand, transportation costs, and the capacity of the distribution centers were considered uncertain.

After modeling the problem, GWO, ALO and PSO algorithms were used to solving the problem. First, a sample problem at a small size was designed and the output variables were studied by Cplex. After revising the output variables and validating the model, the meta-heuristic algorithms of GWO, ALO and PSO were applied in order to solve the large sizes sample problems. First, the problem was studied through the mentioned algorithms and the proximity of the objective function means as well as the CPU-time at large sizes indicated the algorithm's high efficiency to solve the sample problem at a large size. The results of the problem-solving at large sizes indicated the high efficiency of GWO and ALO against PSO. To compare the indexes of these algorithms (means of the total costs and CPU-time), T-test was used to study the significance of the mean indexes derived from the meta-heuristic algorithms and it showed that there is no significant difference the achieved objective function and CPU-time of meta-heuristic algorithms. Therefore, to choose the most efficient algorithm regarding the comparative indexes, other method such as TOPSIS was used. The results of using TOPSIS indicated the efficiency of GWO by gaining the optimum weight of 0.612.

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