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Optimization of location-routing-inventory problem for perishable products with WOA and ALO algorithms

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Abstract
This paper discusses the modeling of a location-routing-inventory problem for perishable products. The model presented in this paper includes a three-echelon supply chain of suppliers, distribution centers, and retailers. Supplier selection, assigning suppliers to distribution centers and retailers, vehicle routing and economic order quantity, lead time, and confidence inventory are the main decisions of the problem. These decisions are aimed at optimizing the total supply chain network costs. The nonlinear model presented in this article has been solved using two algorithms, WOA and ALO, in 12 sample problems. The results show that the solving speed of these algorithms and the high quality of the obtained answers are very high compared to the exact method. So, the maximum percentage of relative difference between the obtained results is less than 1%. The sensitivity analysis on the perishability rate also shows the increase in total costs in line with the increase in this parameter. By examining the outputs of 12 sample problems in large size, the WOA showed its efficiency compared to the ALO in terms of two indicators of average total costs and CPU time.
Keywords: location-routing-inventory, perishable products, distribution-routing network, meta-heuristic algorithms

1-Introduction
Researchers and practitioners often classify supply chain decisions into strategic, tactical, and operational based on the time horizon of impact. Strategic decisions have a longer time horizon of impact, which can even take years, because they deal with decisions that cannot be easily changed, such as the location of facilities. Tactical decisions have a time horizon of several months and include planning aspects related to inventory management. Finally, operational decisions are made daily, with almost immediate effect, and include distribution decisions. Historically, these decisions are reviewed separately. Each entity in the supply chain tries to minimize the costs incurred in the same facility without considering the consequences of these actions on the upstream or downstream units of the supply chain (Navazi et al., 2023). While this approach ensures that cost is minimized for each level, the sum of all costs throughout the supply chain may not be minimal. A situation in which each level tries to maximize its benefits regardless of the other levels leads to local optimization and sometimes suboptimal systems and excessive costs (Hiassat et al., 2017).
Recently, supply chain managers and researchers have realized the importance of integrating supply chain decisions. Many researchers have shown significant savings by considering a combination of the above decisions in a single model. Many models presented in the literature

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combine two supply chain decisions into a single model. These models are location-inventory models, location-routing and inventory-routing models (Komijani & Sajadieh, 2024). However, few models integrate all three decisions and solve them simultaneously. In other words, location-inventory-routing models have not been widely studied (nozari & Nahr, 2022).

Due to the increasing trend in supply chain management issues, the combination of location, routing and inventory of perishable products has become very important in the industry. Perishable products, due to the limited time allowed for storage, bring more challenges to the supply chain. In general, a perishable product is a product that loses its value over time, such as dairy products, fruits, vegetables, blood, materials chemical etc. (Liu et al., 2021). Deterioration of goods, in addition to causing economic losses to companies, also increases waste from an environmental point of view, resulting in more pollution of the environment. In this situation, the manufacturer can return the expired products and properly manage them for disposal or recycling by creating a suitable collaboration process with retailers and sharing information related to demand and inventory. In this way, it provided the basis for saving costs, reducing environmental pollution, and using fewer natural resources (Barma et al., 2022).

Therefore, applying the concepts and principles of logistics and supply chain for various organizations, especially the industries related to perishable items, seems to be necessary, which has attracted the attention of many researchers. In addition to the need to design a closed loop supply chain, the integration of decision making in the supply chain has become one of the most important aspects of the supply chain management system (Karimi et al., 2023). This concept examines the dependence between the location of the facility, the allocation of suppliers and customers to the facility, the structure of the transportation system and their routing, and the inventory control system (Ghahremani-Nahr et al., 2022).

The location-routing-inventory problem is one of the most widely used problems in the design of supply chain networks to improve and reduce costs and increase competitiveness (Hu et al., 2018). Which route and by which place the product is chosen to be transported to the destination and how much of it is kept is of great importance to reduce costs (Ghaderi et al., 2024). This issue is particularly important in the supply chain of perishable goods due to the specific conditions of the product. Because in addition to the cost of lost sales due to the lack of timely supply of demand, the cost of maintaining the product, quality loss and spoilage of the product will also be borne. In fact, location, routing, and inventory decisions are highly interdependent, and their integration leads to coherence between different decision-making levels and enables the company to manage logistics system processes in an effective manner (Ji et al., 2020).

Based on the materials presented in this article, a location-routing-inventory model is presented in the supply chain network for perishable products, whose main goal is to minimize the costs of the entire supply chain. Cplex method and WOA and ALO algorithms are also used to solve the mathematical model.

2- Literature Review

Allocation of location, vehicle routing, and inventory control are among the major issues in distribution network design. Traditionally, these planning steps are followed in order, where location allocation is determined before vehicle routing and inventory control. Due to the interdependence among these problems, an increasing number of researchers have developed integrated models for the above problems, such as location-routing problems, routing-inventory problems, and location-routing-inventory problems. Suppliers can reduce total systematic costs and improve operational efficiency by jointly optimizing these decisions. Combining vehicle routing and inventory management problems creates a complex optimization in logistics called routing-inventory problems (Aliahmadi & Nozari, 2023 , Nozari et al., 2023).

Chitsaz et al. (2016) discussed a rotating routing-inventory model, which is proposed to determine a rotating schedule for the distribution of a single product to a number of customers. This model was divided into two subproblems and solved by a two-step heuristic algorithm. Markov et al. (2018) presented a model of vehicle and inventory routing problems. A variety of realistic features such as multi-period and unpredictable events were also considered. Sayarshad et al. (2018) presented a hybrid optimization model of inventory management, vehicle routing, and pricing strategies in which demand and inventory are related to forecasting future situations. Keyvan et al. (2019) considered the horizontal verification of suppliers in the optimization of vehicle routing and inventory control and showed that expanding the market size significantly reduces the total cost. The location-routing-inventory problem optimizes the combination of location, vehicle routing and inventory control (Aliahmdi et el., 2013).

Rabbani et al. (2021) presented a multi-objective optimization model for a sustainable municipal solid waste management system, with an emphasis on recycling and waste-to-energy technologies. The new feature of this study is the combination of pricing decisions in traditional waste management problems of location-allocation-routing-inventory. Yuchi et al. (2021) investigated a location-inventory-routing problem in a closed-loop supply chain that considers stochastic demands as well as stochastic customer returns. Alvarez et al. (2022) investigated the production routing problem for perishable products with fixed shelf life and gradual decay. They investigated perishability in the form of shelf life and product decay and further analyzed the effect of different decay rates on the cost structure of the problem and the importance of transfers to manage perishability throughout the system. Tirkolaee and Aydin (2022) have proposed two integrated multi-objective mixed integer linear programming (MILP) models for problem formulation. On-time delivery is considered as the main factor determining the performance of the model due to the perishability of the products. Song and Wu (2023) have investigated two location-inventory problems (LIP) and location-inventory-routing problem (LIRP). Mixed integer nonlinear programming model is used for LIP and mixed integer linear programming model is used for LIRP. Aghighi et al. (2023) investigated an extended Location-routing-inventory problem for perishable products, in which a two-phase hybrid mathematical model is developed. Nasiri et al., (2023) proposed an optimization model to design a green location-inventory-routing model with simultaneous P&D under disruption risks. The proposed model aims to minimize lost demands, and the network’s total costs are considered budget constraints. Eslamipoor (2024) investigated a three-level supply chain. It consists of a factory with uncapacitated inventory that produces one type of product at the first level, several distribution centres at the second level that act as distributors, and a group of customers scattered in different geographical locations at the third level.

Literature review shows that different models of location-routing-inventory in the supply chain have been designed and solved. By developing previous models, this article has designed this issue for perishable products and has used WOA and ALO to optimize total costs and achieve optimal decisions.

3-Mathematical Model

The mathematical model presented in this paper corresponds to Figure (1) in which a set of suppliers, distribution centers and retailers are present. In this network, suppliers send raw materials needed to produce products to distribution centers. Distribution centers supply products based on the reorder point and ordering time and send them to retailers in the form of routing. The main goal of the model presented in this article is to minimize total costs. In order to optimize total costs, decisions such as locating suppliers, determining the optimal amount of inventory of distribution centers and retailers, and optimal transportation routing are taken.

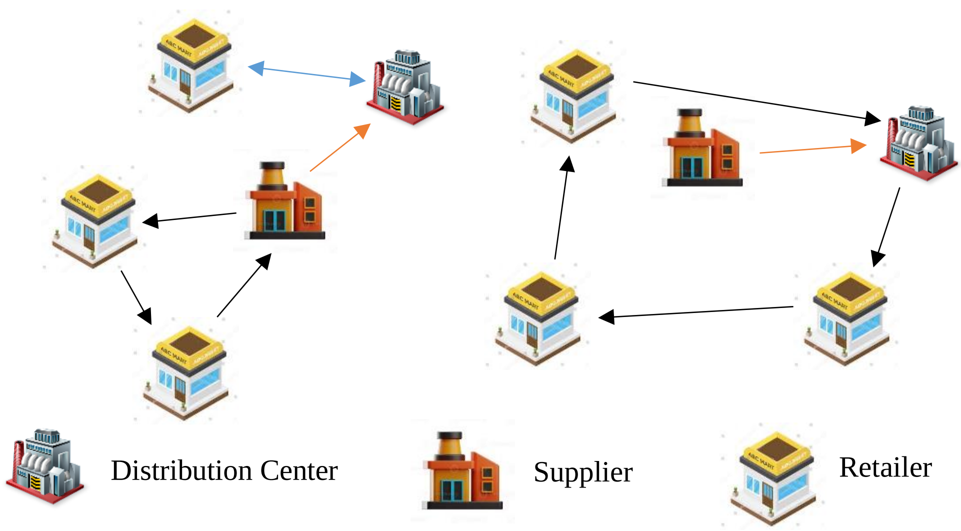


Figure 1. Location-routing-inventory model under study

Sets

N	Retailer $n, l \in N$
M	Distribution center $m \in M$
B	Supplier $b \in B$
F	Product $f \in F$

Parameters

A_{fm}	Ordering cost of product $f \in F$ from distribution center $m \in M$
H_{fm}	Inventory cost of product $f \in F$ from distribution center $m \in M$
h_{fn}	Inventory cost of product $f \in F$ from retailer $n \in N$
a_{fn}	Ordering cost of product $f \in F$ from retailer $n \in N$
μ_{fn}	Daily demand of product $f \in F$ from retailer $n \in N$
σ_{fn}	standard deviation of μ_{fn}
θ_f	Perishability rate of the product $f \in F$
ρ_{nl}	Correlation coefficient of demand of retailer $n \in N$ and retailer $l \in N$
l_{fmb}	Lead time of product $f \in F$ distribution center $m \in M$ from supplier $b \in B$
l_{fnm}	Lead time of product $f \in F$ of retailer $n \in N$ from distribution center $m \in M$
l_{fnb}	Lead time of product $f \in F$ of retailer $n \in N$ from supplier $b \in B$
cap_{fm}	Inventory capacity of product $f \in F$ from distribution center $m \in M$
p_b	Fixed cost of selection of $b \in B$
q_{mb}	The fixed cost of building the route between the distribution center $m \in M$ and the supplier $b \in B$
t_{fmb}	Transporting cost of product $f \in F$ between distribution center $m \in M$ and supplier $b \in B$
t_{fnm}	Transporting cost of product $f \in F$ between retailer $n \in N$ and distribution center $m \in M$
t_{fnb}	Transporting cost of product $f \in F$ between retailer $n \in N$ and supplier $b \in B$
λ	Number of working days in a year
o_f	Perishability cost of product $f \in F$
Z_α	Cumulative probability distribution function
$[a_n, b_n]$	Time window in delivering products to retailer $n \in N$
$[c_n, d_n]$	Time window in delivering products to distribution center $m \in M$

Decision Variables

X_{nm}	1; if retailer $n \in N$ has received service from distribution center $m \in M$. 0; otherwise
Y_{mb}	1; if distribution center $m \in M$ has received service from supplier $b \in B$. 0; otherwise
Z_{nb}	1; if retailer $n \in N$ has received service from supplier $b \in B$. 0; otherwise

W_b	1; if supplier $b \in B$ is selected. 0; otherwise
D_{fm}	Actual daily demand of product $f \in F$ from distribution center $m \in M$
U_{fm}	Variance of D_{fm}
SS_{fm}	Safety stock of product $f \in F$ from distribution center $m \in M$
SS_{fn}	Safety stock of product $f \in F$ from retailer $n \in N$
R_{fm}	Reorder point of product $f \in F$ from distribution center $m \in M$
R_{fn}	Reorder point of product $f \in F$ from retiler $n \in N$
INV_{fm}	Total inventory of product $f \in F$ from distribution center $m \in M$
INV_{fn}	Total inventory of product $f \in F$ from retiler $n \in N$
Q_{fm}	Optimal order point of product $f \in F$ from distribution center $m \in M$
Q_{fn}	Optimal order point of product $f \in F$ from retiler $n \in N$

Based on the defined symbols, the location-routing-inventory model for perishable products is as follows.

$$\sum_{b\in B} p_b.W_b + \sum_{m\in M}\sum_{b\in B} q_{mb}.Y_{mb} + \sum_{m\in M}\sum_{b\in B}\sum_{n\in N}\sum_{f\in F}\frac{\lambda\mu_{fn}.X_{nm}.t_{fmb}.Y_{mb}}{\left(1-\theta_f\right)^2} + \tag{1}$$
$$\sum_{m\in M}\sum_{n\in N}\sum_{f\in F}\frac{\lambda\mu_{fn}.X_{nm}.t_{fnm}}{\left(1-\theta_f\right)} + \sum_{b\in B}\sum_{n\in N}\sum_{f\in F}\frac{\lambda\mu_{fn}.Z_{nb}.t_{fnb}}{\left(1-\theta_f\right)} +$$
$$\sum_{m\in M}\sum_{f\in F} H_{fm}.INV_{fm} + \sum_{n\in N}\sum_{f\in F} h_{fn}.INV_{fn} + \sum_{m\in M}\sum_{f\in F}\frac{\lambda.A_{fm}.D_{fm}}{Q_{fm}} +$$
$$\sum_{n\in N}\sum_{f\in F}\frac{\lambda.a_{fn}.\mu_{fn}.\sum_{b\in B} Z_{nb}}{Q_{fn}\left(1-\theta_f\right)} + \sum_{m\in M}\sum_{b\in B}\sum_{n\in N}\sum_{f\in F}\frac{\lambda.o_f.\theta_f.\mu_{fn}.X_{nm}.Y_{mb}}{\left(1-\theta_f\right)^2} +$$
$$\sum_{m\in M}\sum_{n\in N}\sum_{f\in F}\frac{\lambda.o_f.\theta_f.\mu_{fn}.X_{nm}}{\left(1-\theta_f\right)} + \sum_{b\in B}\sum_{n\in N}\sum_{f\in F}\frac{\lambda.o_f.\theta_f.\mu_{fn}.Z_{nb}}{\left(1-\theta_f\right)}$$

$s.t.$:

$$Y_{mb} \le W_b, \forall m \in M, b \in B \tag{2}$$
$$Z_{nb} \le W_b, \forall n \in N, b \in B \tag{3}$$
$$X_{nm} \le \sum_{b\in B} Y_{mb}, \forall n \in N, m \in M \tag{4}$$
$$\sum_{n\in N} \mu_{fn}.X_{nm} \le cap_{fm}, \forall m \in M, f \in F \tag{5}$$
$$\sum_{m\in M} X_{nm} + \sum_{b\in B} Z_{nb} = 1, \forall n \in N \tag{6}$$
$$\sum_{b\in B} Y_{mb} \le 1, \forall m \in M \tag{7}$$
$$Q_{fn} = \sqrt{\left(\frac{2\lambda.a_{fn}.\mu_{fn}.\sum_{b\in B} Z_{nb}}{h_{fn}\left(1-\theta_f\right)}\right)}, \forall n \in N, f \in F \tag{8}$$

$$Q_{fm} = \sqrt{\left(\frac{2\lambda . A_{fm} . D_{fm}}{H_{fm}}\right)}, \forall m \in M, f \in F \quad (9)$$

$$D_{fm} = \frac{\sum_{n \in N} \mu_{fn} . X_{nm}}{1 - \theta_f}, \forall m \in M, f \in F \quad (10)$$

$$U_{fm} = \sum_{n \in N} \sum_{l \in N} \rho_{nl} . \sigma_{fn} . \sigma_{fl} . X_{nm} . X_{lm}, \forall m \in M, f \in F \quad (11)$$

$$L_{fm} = \sum_{b \in B} l_{fmb} . Y_{mb}, \forall m \in M, f \in F \quad (12)$$

$$SS_{fm} = Z_\alpha \sqrt{\sum_{b \in B} U_{fm} . l_{fmb} . Y_{mb}}, \forall m \in M, f \in F \quad (13)$$

$$R_{fm} = SS_{fm} + \sum_{b \in B} l_{fmb} . Y_{mb} D_{fm}, \forall m \in M, f \in F \quad (14)$$

$$INV_{fm} = \frac{Q_{fm}}{2} + SS_{fm}, \forall m \in M, f \in F \quad (15)$$

$$SS_{fn} = Z_\alpha . \sigma_{fn} . \sqrt{\sum_{b \in B} l_{fnb} . Z_{nb}}, \forall n \in N, f \in F \quad (16)$$

$$INV_{fn} = \frac{\mu_{fn} . \sum_{m \in M} X_{nm} . l_{fnm}}{2} + \frac{Q_{fn}}{2} + SS_{fn}, \forall n \in N, f \in F \quad (17)$$

$$R_{fn} = SS_{fn} + \sum_{b \in B} \mu_{fn} . l_{fnb} . Z_{nb}, \forall n \in N, f \in F \quad (18)$$

$$a_n \le \sum_{m \in M} t_{fnm} . X_{nm} + \sum_{b \in B} t_{fnb} . Z_{nb} \le b_n, \forall n \in N, f \in F \quad (19)$$

$$c_m \le \sum_{b \in B} t_{fmb} . Y_{mb} \le d_m, \forall m \in M, f \in F \quad (20)$$

$$X_{nm}, Y_{mb}, , Z_{nb}, W_b \in \{0,1\} \quad (21)$$

$$D_{fm}, U_{fm}, SS_{fm}, SS_{fn}, R_{fm}, R_{fn}, INV_{fm}, INV_{fn}, Q_{fm}, Q_{fn} \ge 0 \quad (22)$$

Equation (1) shows the total costs of the location-routing-inventory problem. In this regard, there are costs such as the establishment of a supplier, transportation costs, costs of ordering and maintaining perishable products, costs of product failure. Equation (2) shows that if a supplier is selected, services can be provided from that supplier to the distribution centers. Equation (3) also shows that if a supplier is selected, it is possible to provide services to retailers from that supplier. Equation (4) If the distribution center provides services to a certain retailer, it must have received the products and services from the supplier in advance. Equation (5) guarantees that the distribution center cannot distribute products beyond its capacity. Equation (6) guarantees that each retailer can receive goods and products from only one distribution center. Equation (7) guarantees that each distribution center can receive goods and services from at most one supplier. Equations (8) and (9) show the optimal order quantity of perishable products for the distribution center and the retailer. Equations (10) and (11) calculate the demand for perishable products. In these relationships, the daily demand of products for retailers follows a normal distribution function in the form of $(\mu_{fn}, \sigma_{fn}^2)$. Therefore, according to the interactions between retailers, the product demand in the distribution center will follow a multivariate normal distribution (D_{fm}, U_{fm}). Equation (12) shows the lead time of the distribution center. Equations (13) and (14) calculate the confidence inventory and re-travel point for a distribution center. Equation (15) shows the total inventory of the distribution center, including the inventory of the trust and the seller's inventory. Equation (16) shows the retailer's confidence inventory and Equation (17) shows the retailer's total inventory. Equation (18) shows the retailer's reorder point. Equations (19) and (20) show the time window for timely delivery of perishable products to distribution centers and retailers. Equations (21) and (22) show the type of decision variables of the problem.

4- Results

After presenting the location-routing-inventory mathematical model, in this section the analysis of different sample problems with WOA and ALO has been done. Therefore, 12 sample problems in different sizes have been designed according to Table (1).

Table 1. Size of sample problems in large size

Sample Problem	*N*	*M*	*B*	*F*	*Sample Problem*	*N*	*M*	*B*	*F*
1	6	3	4	2	7	40	15	15	4
2	15	5	5	2	8	50	15	15	4
3	20	8	8	2	9	60	20	20	4
4	25	8	8	3	10	70	20	20	5
5	30	12	12	3	11	80	25	25	5
6	35	12	12	3	12	100	25	25	5

Also, due to the lack of access to real data, random data according to the uniform distribution function has been used to value the problem's parameters. Table (2) shows the random values of the problem's parameters based on the uniform distribution function.

Table 2. Interval limits of problem parameters based on uniform distribution function

Parameter	Value	Parameter	Value	Parameter	Value
A_{fm}	~U[20,30]	t_{fmb}, t_{fnb}	~U[30,40]	θ_f	~U[0.05,0.1]
H_{fm}	~U[0,2]	t_{fnm}	~U[15,20]	ρ_{nl}	~U[0.8,1.2]
h_{fn}	~U[0,1.5]	l_{fmb}, l_{fnb}	~U[3,15]	q_{mb}	~U[50,100]
a_{fn}	~U[10,18]	l_{fnm}	~U[1,5]	o_f	~U[3,5]
μ_{fn}	~U[50,60]	cap_{fm}	~U[300,500]	Z_α	1.96
g_b	~U[50,300]	p_b	~U[1000,1200]		

After setting the parameters of the problem, each sample problem is solved 5 times by ALO and WOA and the total costs of the problem and CPU-time are shown in Table (3) and Figure (2).

Table 3. Average total cost and CPU-time

Sample Problem	WOA		ALO		Cplex	
	Total Cost	CPU-time	Total Cost	CPU-time	Total Cost	CPU-time
1	706684.1	24.67	706697.4	21.34	706527.6	423.35
2	929932.2	36.97	935715.9	32.69	935018.6	776.81
3	1023541.2	53.60	1034864.3	47.10	1003549.4	1212.46
4	1101518.4	78.67	1119866.5	68.94		
5	1190815.5	110.37	1195466.4	98.73		
6	1265868.7	148.67	1274567.9	134.10		
7	1328013.0	190.33	1325590.0	172.34		
8	1382893.0	239.87	1395886.4	215.84		
9	1444326.1	290.22	1465875.6	260.44		
10	1508530.6	346.09	1534765.7	315.21		
11	1650028.4	406.57	1630178.3	370.69		
12	1693918.3	477.26	1698766.3	432.79		

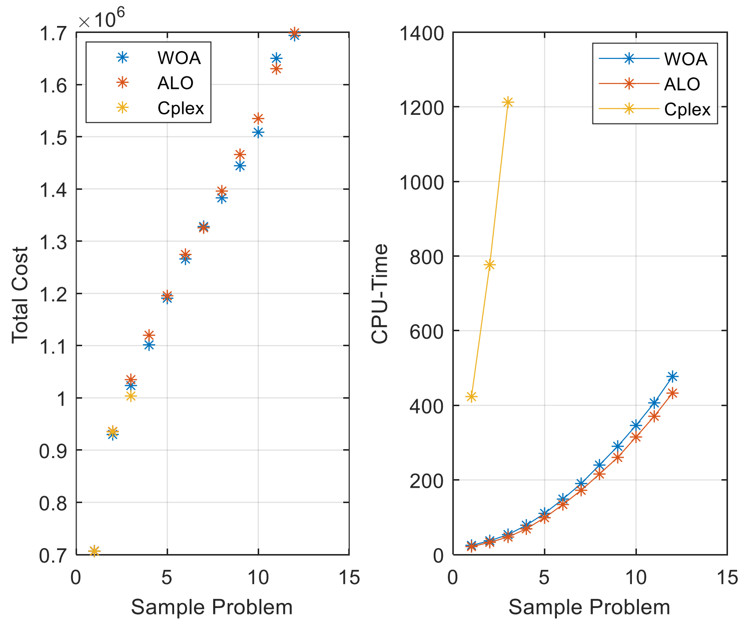


Fig. 2. Variations of the objective function and CPU-time

Based on the obtained results, it can be seen that the time to achieve the optimal value of the objective function by Cplex is very high and this method is not highly efficient in solving the sample problems in larg size. While WOA and ALO have reached near-optimal values in a shorter time than Cplex. In this analysis, what can be seen is the high efficiency of WOA in achieving the near-optimum objective function and the high efficiency of ALO in achieving the results.

To check the output of the problem, Figure (3) shows the supply and distribution network of perishable products for the first sample problem.

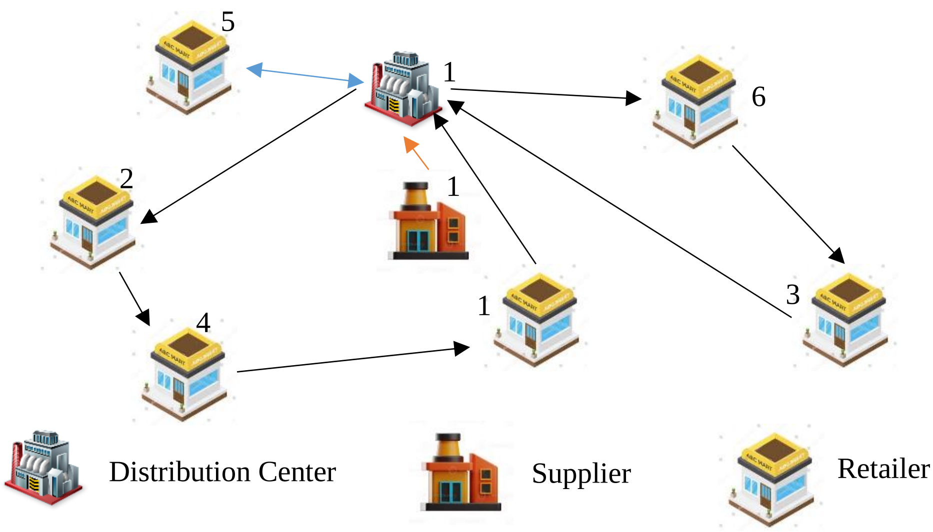


Fig. 3. Location-routing of perishable products

According to Figure (3), it can be seen that supplier number 1 is responsible for supplying raw materials. This center is directly connected with retailer 5 and distribution center #1. Also, the method of vehicle routing in the distribution of perishable products between the distribution center and retailers is shown. Table (4) shows the amount of economic order by retailers and distribution centers from the supplier.

Table 4. The economic order value of retailers and distribution centers from the supplier

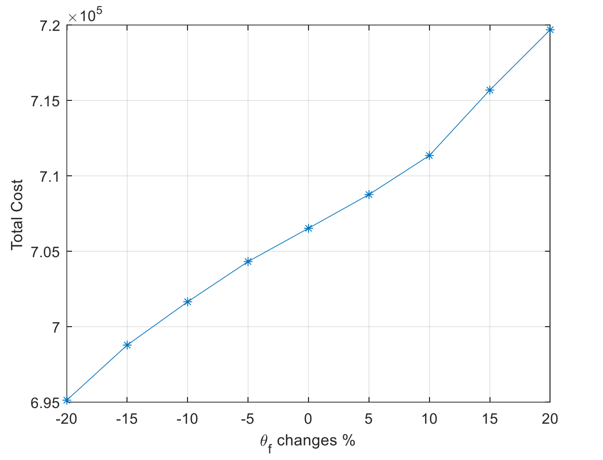
Product	Retailer 5	Distribution Center 1
1	266.319	679.190
2	232.834	601.645

Table (5) also shows the accumulated inventory of retailers for two types of perishable products considered.

Table 5. Accumulated inventory of retailers of perishable products

Retailer	Product 1	Product 2
1	125.936	115.674
2	79.450	76.543
3	88.268	46.314
4	99.507	128.507
5	492.993	556.457
6	97.380	116.482

The perishability rate of products is the most important parameter that affects the economic order amount, storage of products in the warehouse and other decision-making variables. Therefore, Figure (4) shows the changes in the values of total cost at different perishability rates between -20% and +20%.



θ_f %	*Total Cost*
-20 %	695132.7
-15 %	698786.7
-10 %	701654.7
-5 %	704321.2
0	706527.7
+5 %	708762.3
+10 %	711348.7
+15 %	715687.2
+20 %	719687.4

Fig. 4. Changes in the Total cost under the changes in perishability rate

According to the results of Figure (4), it can be seen that with the increase in the perishability rate, due to the perishability of products and the need to meet the exact demand of retailers, the amount of the economic order has increased and this has led to an increase in total costs.

In reviewing the results, it was observed that each algorithm was more efficient in obtaining an index. Therefore, to check the significance between the average results obtained from solving sample problems in large size by WOA and ALO, T-Test statistical test was used at 95% confidence level. In this way, if the P-Value is less than 0.05, it indicates the existence of a significant difference between the average indices of the comparison between the two solution methods. Table (6) shows the summary of the results of the T-Test statistical test.

Table 6. The results of the T-Test in comparison between the indicators

Index	Difference	95% CI for difference	T-Value	P-Value
Total Cost	7681	(-242399, 257761)	0.06	0.950
CPU-time	19.4	(-104.2, 143.1)	0.33	0.747

The results of the T-Test statistical test show that there is no significant difference between the average comparison indices between WOA and ALO. Therefore, to choose the most efficient algorithm to solve the current problem, TOPSIS method has been used. In this method, the average value of the objective function and the CPU-time are considered as the evaluation matrix. The output of the TOPSIS method shows that the WOA utility weight is equal to 0.648 and the ALO utility weight is equal to 0.352. Therefore, the WOA is suitable for solving the location-routing-inventory problem for perishable products.

5- Conclusion

In this paper, a location-routing-inventory problem for perishable products was investigated and modeled. The main purpose of presenting the mathematical model of this problem was to achieve a distribution network of perishable products along with determining the reorder point and warehouse inventory. Several strategic and tactical decision variables have been used to design this model, which includes locating suppliers, assigning suppliers to distribution centers, and vehicle routing between distribution centers and retailers. To achieve the above objectives, the objective function of minimizing total costs was considered. This led to the design of a non-linear model, which WOA and ALO were considered to solve. By analyzing 12 sample problems in large size, it was observed that the Cplex method did not have a high efficiency in solving sample problems in large size, and the proposed algorithms achieved close to optimal solutions in a much shorter CPU-time. So that the maximum percentage of relative difference between the proposed algorithms and Cplex was less than 1%. Examining the output of the model and analysis on the parameter of perishability rate showed that the increase of this parameter increases the total supply chain network costs. The results of the T-Test statistical test show that there is no significant difference between the average comparison indices between the two proposed algorithms. Therefore, to select the most efficient algorithm, the TOPSIS method was used, as a result of which WOA achieved a higher index than this method. The authors suggest that reliability in the transfer of perishable products between different levels be used in future research. Also, the development of meta-heuristic algorithms and the consideration of stability objective functions are also proposed as other suggestions.

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