Original Research

A Location-Routing-Inventory Model for Perishable Items Using Fresher First and Older First Inventory Management Policies

Shima Harati[1]. Emad Roghanian[2*]. Ashkan Hafezalkotob[1]. Amir Abbas Shojaie[1]

Received: 2020-12-25 / Accepted: 2021-08-21 / Published online: 2021-08-21

* Corresponding Author, e_roghanian@kntu.ac.ir
1- Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran.
2- Department of Industrial Engineering, K. N. Toosi University of Technology, Tehran, Iran.

Abstract
The purpose of the current research is to present a location-routing-inventory model for perishable products. The presented model is applied in a two-stage structure. The first-stage decisions confirm the establishment of distribution centers, whereas the second-stage decisions determine the other variables of the problem. The studied model also examines the location-routing-inventory problem along with the issue of perishability. For a better management of inventory, it has been used under the names of fresher first and older first policies. In the fresher first policy, the fresher items have a priority to be sent to the customer, whereas in the older first policy, the items with a longer age have the priority to be sent to the customer. The summary of the results of the models demonstrates that among the free, fresher first, and older first policies, it is the free policy that offers a higher profit function to the customer than the other two policies since it is more flexible and general, and encompasses these two extremes. The free policy lets the model determine which items to sell at any given time period in order to maximize profit. This means that depending on the parameter settings, one may prefer to spoil some items and sell fresher ones because they generate higher revenues. It imposes fewer constraints to the model. Moreover, in the older first policy, since the older items reach the customers sooner than the other items, the number of the expired items is reduced. However, this policy brings the lowest revenue to the customer. In the fresher first policy, since the fresher items are sold first and then the older items are sold, the number of the expired items is increased along the customer horizon. Nevertheless, the customer obtains more revenue compared with the older first policy. The summary of the results of the models indicate that among the free, fresher first and older first, the free policy provides the customer with more profit than the other three policies since it imposes fewer constraints on the model.

Keywords: Inventory locating, Perishable items, Inventory management policy, Routing

INTRODUCTION

The purpose of the current research is to present a location – routing – inventory model for perishable products. Inventory control constitutes an important logistics operation, especially when products have a limited shelf life. Keeping the right inventory levels guarantees that the demand is satisfied without incurring unnecessary holding or spoilage costs. Several inventory control models are available (Axsäter, 2006), many of which include a specific treatment of perishable products (Nahmias, 2011). Several inventory management models have been specifically derived for perishable items, such as the periodic review with minimum and maximum order quantity of Haijema (2011), and the periodic review with service level considerations of Minner and Transchel (2010). Reviews of the main models and algorithms in this area can be found in Nahmias (2011) and in Karaesmen et al. (2011). A unified analytical approach to the management of supply chain networks for time-sensitive products is provided in Nagurney et al. (2013). Efficient delivery planning can provide further savings in logistics operations. The optimization of vehicle routes is one of the most developed fields in operations research (2009). The integration of inventory control and vehicle routing yields a complex optimization problem called inventory-routing whose aim is to minimize the overall costs related to vehicle routes and inventory control. Recent overviews of the inventory-routing problem (IRP) are those of Andersson et al. (2010) and of Coelho et al. (2014).

In such a context, according to Coelho and Laporte (2014) three different selling priority policies can be envisaged. The first one consists of applying a fresh first (FF) policy by which the retailer always sells the fresher items first. This policy ensures a longer shelf life and increases utility for the customers but, at the same time, yields a higher spoilage rate. The second policy is the reverse. Under an old first (OF) policy, older items are sold first, which generates less spoilage, but also less revenue. The third policy, which we introduce in our model, is more flexible and general, and encompasses these two extremes. The optimized priority (OP) policy lets the model determine which items to sell at any given time period in order to maximize profit. This means that depending on the parameter settings, one may prefer to spoil some items and sell fresher ones because they generate higher revenues.

Although they are similar, FF and OF policies are different from the traditional FIFO and LIFO policies common in inventory management. Under a FIFO policy, the first product delivered will be the first to be sold. This coincides with an OF policy only if deliveries from the supplier to the retailer is always of fresh items. However, when the supplier delivers products of different ages in different periods, the sequence of deliveries does not necessarily coincide with the ages of the products in inventory. To illustrate, consider the case where the supplier delivers new items on day one, and three-day old items on day two. Then, on day three, different solutions will be obtained under the OF and the FIFO policies. Indeed, under the FIFO policy, the newer items (delivered on day one) will be sold first, but the older items (delivered on day two) will be selected under an OF policy.

A three-level supply chain for dairy products is examined in the current research. The raw milk supplier is the first level. The second level of the supply chain comprises the dairy factories which collect milk from the suppliers and process and send it to the consumer centers which are the third level of the supply chain. One of the principal aims of the current research is to set up a suitable connection and routing among the supply chain levels as well as to locate the distribution facilities by taking transportation into account. In the studied problem, it is very crucial to locate the middle level (the dairy supplier) due to the dispersion of raw milk production and consumer centers. In the current research, setting up production centers is regarded as a variable and is resolved based on the other parameters of the problem. It is not possible to decide for all the variables simultaneously because decisions about setting up a dairy production factory are associated with strategic-tactical levels, whereas routing and determining the transfer rate are associated with tactical-operational levels. To deal with this problem in this study, a two-stage decision-making method is employed. The decisions are first made with respect to the establishment and setup of the dairy factory, while other routing-inventory decisions are made in the next stage. Because the considered items are perishable, the model has been investigated in the periodic mode. When one period passes to the next, if a product still remains in the warehouse, its shelf life is enhanced by one unit. Different shelf lives of the products could lead to different revenues for the system.

Several scholars such as Liu et al. (2015), Shah (2017), Onggo et al. (2019), Yang and Wee (2002), Rau et al. (2003), and Yavari and Geraeli (2019) have investigated the idea of perishable goods in supply chains. One of the useful strategies in this regard is inventory management by the seller. In this strategy, the manufacturer decides not only about the quantity and time of inventory renewal but also about the system by contemplating the necessity of an inventory renewal period for the consumers. Considering the significance of the perishable goods and the supply chain, a few scholars have paid attention to the integrity of the chain along with perishable goods. Considering inventory and routing problems, Seyedhosseini and Ghoreyshi (2014) proposed an integrated model for the production and distribution of perishable products.

Tavakkoli Moghaddam et al. (2019) designed a mathematical model for the reverse supply chain of perishable goods, taking into account the sustainable production system. In this research, four objective functions were considered to maximize profitability and the level of satisfaction with the use of technology, minimize costs and measure environmental impacts.

Chandra Panda et al. (2020) propose A credit policy approach in a two-warehouse inventory model for deteriorating items with price- and stock-dependent demand under partial backlogging. In this research, trade credit facility is taken in the perspective of retailer, and all the possible cases and subcases of the model are discussed and solved using lingo 10.0 software. The results of sensitivity analysis prove the effectiveness of the proposed model.

Abou Chakra and Ashi (2020) in a research firstly, to assess and compare the performance of design/bid/build and design/build projects in Lebanon; secondly, to compare the results with the performance of equivalent systems in the Far East and the USA, in order to identify the similarities between Lebanon and these countries. Seven performance indicators were identified in terms of cost, time, quality, communication, risk and safety to evaluate the performance of 102 residential buildings and tower projects completed in Lebanon. Means and medians of these performance indicators were compared to identify which delivery system performs better regarding each indicator. The results presented in this study show some agreements between different performance indicators when applied to principal project delivery systems in the selected countries.

Yu et al. (2011) investigated the perishability of products in the integrated two-level supply chain and made an integrated model for perishable goods. In their model, retailer demand has been considered to be constant and deterministic, perishability has been assumed for the final product, and the optimum values have been calculated by employing a heuristic and metaheuristic hybrid approach so that the supply chain profit can be maximized. Shaabani and Kamalabadi (2016) proposed a simulated annealing model for the supply chain with some consumers buying several perishable products. Hsu et al. (2007) proposed a routing problem with a time window for perishable products. Seyedhosseini et al. (2016) investigated the problem of perishable products with stochastic demand for a two-level supply chain. The main goal of the present research is to propose a robust two-stage stochastic location-routing-inventory model for perishable products. The first type includes products whose value does not change until a certain date, and then goes down to zero almost immediately. This is the case of products whose utility eventually ceases to be valued by the customers, which quickly become obsolescent after a given date or when a new generation of products enters the market. However, this is more a case of obsolescence than perishability. Even though these items may still be in perfect condition, they are simply no longer useful. Within the same category, we find products with an expiry date, such as drugs, yogurt and bottled milk. These products can be consumed whether they are top fresh or a few days old, but after their expiry date, they are usually deemed unfit for consumption. The second type includes products whose quality or perceived value decays gradually over time. The models introduced can handle both types of products without any ad hoc modification. Raafat (2011) describes a stochastic model in which the deterioration is a function of the on-hand inventory level. Our model does not work under the assumption of a random lifetime, Chao et al. (2019) proposed a mixed-integer programming model for their location–routing–inventory problem and used the time-windows method and a hybrid heuristic algorithm to solve it. Khalili-Damghani et al (2015) presented a bi-objective location-routing mixed integer model to distribute perishable items in supply chains and used NSGA-II and ε-constraint to solve it.

In the present study, the following research gaps were found after previous researches were reviewed:

- The time horizons of most of the decision-making models are infinite, however, these models have been examined in the scheme of economic ordering or economic production models.
- So far, no two-stage model which deals with both strategic and operational decisions concurrently has been studied in the literature.
- Most former researches have a specific demand function, however, a simple demand function is inadequate for perishable products due to their distinct properties. Most demand functions in the literature are dependent on the price, time, or expiration period, while the current research proposes a flexible approach for the type of demand.
- There are only a limited number of studies that have investigated the relationship between inventory and routing with respect to perishable items. The present research aims to examine this topic carefully.

MATHEMATICAL MODEL

I. Assumptions

In the present study, there are 13 assumptions. These assumptions are:

1. The chain under study is multilevel and encompasses the levels of suppliers, manufacturers and customers.
2. The studied chain is multi-period and multi-product.
3. The locations of the suppliers and retailers are known, however, the location of the factory is determined by the model.
4. Routing is performed among all the levels.
5. The routing problem is multi-depot and has a specific capacity.
6. The retailer/supplier index with number 1 stands for the factory.
7. The centers and vehicles have a specific capacity.
8. The vehicles are assumed to be heterogeneous.
9. There is a difference between the vehicles which are employed for collecting milk from the suppliers and those utilized for delivering the product to the customers.
10. The products that the customers receive have shelf lives (age).
11. Storing the products in the factory's warehouse for the next period has been assumed possible.
12. For collecting milk from the suppliers, a hard time window has been assumed.

13. The price of the delivered product to the customers is different at any time period based on the shelf life of the product.

II.": sets and indices

Product	j
Supplier	a, a'
Factory	m
Retailer	n, n'
Vehicle for buying milk	p
Vehicle for delivering the product	q
Product age	g
Time period	t
Scenario	s

III. Parameters

The parameters of the mathematical model have been shown below:

$CPTY_{ats}^{sup}$	The capacity of supplier a for supplying milk in time period t under scenario s
$CPTY_{jmt}^{man}$	The capacity of factory m for product j in time period t
$CPTY_{p}^{R-veh}$	The capacity of milk-collecting vehicles p
$CPTY_{q}^{D-veh}$	The capacity of vehicles q employed for delivering the product to the customers
$\omega_{a'a}^{sup}$	The distance between supplier a and supplier a'
ω_{ma}	The distance between factory m and supplier a
$\varpi_{n'n}^{ret}$	The distance between retailer n and retailer n'
ϖ_{mn}	The distance between factory m and retailer n
$\omega T_{pa'a}^{sup}$	The time period between supplier a and supplier a' by vehicle p
ωT_{pma}	The time period between factory m and supplier a by vehicle p
ξ	The time window for collecting milk from the suppliers
$OPMN_{m}$	The setup costs of factory m
OPR_{p}	The cost of buying vehicle p
OPD_{q}	The cost of buying vehicle q
PRC_{at}	The price of buying each unit of milk from supplier a in time period t
$PRCC_{jgt}$	The price of selling each unit of product j with age g to the customers in time period t
PH_{jgmt}	The cost of holding each unit of product j with age g in the warehouse of factory m in time period t
PM_{jmt}	The cost of producing each unit of product j by factory m in time period t
PR_{j}	The amount of milk needed for producing each unit of product j
$demand_{jnts}$	The demand of retailer n for product j in time period t under scenario s
λ_{p}^{R}	The amount of fuel used by vehicle p per unit distance
λ_{q}^{D}	The amount of fuel used by vehicle q per unit distance
PRO_{s}	The probability of an event under scenario s
F	The price of each fuel unit
$bigm$	A very big number

IV.Variables

The following are the variables of the mathematical model:

$X^{R}_{ps}\begin{cases}1\\0\end{cases}$	Binary	If vehicle p is bought under scenario s herwise
$X^{D}_{qs}\begin{cases}1\\0\end{cases}$	Binary	If vehicle q is bought under scenario s Otherwise
$Y^{R}_{pa'ats}\begin{cases}1\\0\end{cases}$	Binary	If vehicle p visits supplier a after visiting supplier a' under scenario s in time period t Otherwise
$Y^{D}_{qn'nts}\begin{cases}1\\0\end{cases}$	Binary	If vehicle q visits retailer n after visiting retailer n' under scenario s in time period t Otherwise
$Z^{R}_{pms}\begin{cases}1\\0\end{cases}$	Binary	If vehicle p is assigned to factory m under scenario s Otherwise
$Z^{D}_{qms}\begin{cases}1\\0\end{cases}$	Binary	If vehicle q is assigned to factory m under scenario s Otherwise
$X_{m}\begin{cases}1\\0\end{cases}$	Binary	If factory m is set up Otherwise
Y_{pamts}	Positive	The amount of milk bought by vehicle p belonging to factory m from supplier a in time period t under scenario s
$Z_{jgqmnts}$	Positive	The amount of product j with age g delivered to customer n by vehicle q belonging to factory m in time period t under scenario s
λ_{jmts}	Positive	The amount of product j produced by factory m in time period t under scenario s
α_{jqnts}	Positive	The amount of product j with age g in vehicle q while it is leaving the location of customer n in time period t under scenario s
A_{pats}	Positive	The arrival time of vehicle p to the location of supplier a in time period t under scenario s
ST_{jgmts}	Positive	The amount of product j with age g in the warehouse of factory m in time period t under scenario s

V. Objective function

The costs are minimized by the objective function. These costs comprise factory setup costs, the costs of buying milk-collecting vehicles, the costs of buying vehicles for delivering the product to customers, the costs of buying milk from the suppliers, the costs of holding raw materials in the factory, production costs in the factory, and the costs of fuel used by milk-collecting and product delivery vehicles.

$$
\begin{aligned}
Max\ \ Z^{benefit} = &\sum_{j,g,q,m,n,t,s} PRO_s \times PRCC_{jgt} \times Z_{jgqmnts} - (\sum_m OPMN_m \times X_m + \sum_s PRO_s \times (\sum_p OPR_p \times X_{ps}^R + \\
&\sum_q OPD_q \times X_{qs}^D + \sum_{p,a,m,t} PRC_{at} \times Y_{pamts} + \sum_{j,g,m,t} PH_{jgmt} \times ST_{jgmts} + \sum_{j,g,q,m,n,t} PM_{jmt} \times Z_{jgqmnts} + \\
&F \times \sum_{p,a'>1,a>1,t} \lambda_p^R \times \omega_{a'a}^{sup} \times Y_{pa'ats}^R + F \times \sum_{p,m,a,>1,t} \lambda_p^R \times \omega_{ma} \times Z_{pms}^R \times (Y_{p1ats}^R + Y_{pa1ts}^R) + \\
&F \times \sum_{q,n'>1,n>1,t} \lambda_q^D \times \omega_{n'n}^{ret} \times Y_{qn'nts}^D + F \times \sum_{q,m,n,>1,t} \lambda_q^D \times \varpi_{mn} \times Z_{qms}^D \times (Y_{q1nts}^D + Y_{qn1ts}^D)))
\end{aligned}
$$

Subjected to:

$$ST_{jgmts} = ST_{j(g-1)m(t-1)s} - \sum_{q,n} Z_{jgqmnts} \qquad \forall j,g>1,m,t>1,s \qquad (1)$$

$$ST_{jgmts} = \lambda_{jmts} - \sum_{q,n} Z_{jgqmnts} \qquad \forall j,g=1,m,t,s \qquad (2)$$

$$\frac{\sum_{p,a} Y_{pamts}}{PR_j} = \sum_{g,q,n} Z_{jgqmnts} \qquad \forall j,m,t,s \qquad (3)$$

$$\sum_{g,q,m} Z_{jgqmnts} \ge demand_{jnts} \qquad \forall j,n,t,s \qquad (4)$$

$$\sum_{p,m} Y_{pamts} \le CPTY_{ats}^{sup} \qquad \forall a,t,s \qquad (5)$$

$$\frac{\sum_{p,a} Y_{gpamts}}{PR_j} \le CPTY_{jmt}^{man} \qquad \forall j,m,t,s \qquad (6)$$

$$\sum_{g,q,n} Z_{jgqmnts} \le CPTY_{jmt}^{man} \qquad \forall j,m,t,s \qquad (7)$$

$$\sum_{a} Y_{pamts} \le CPTY_p^{R-veh} \qquad \forall p,m,t,s \qquad (8)$$

$$\sum_{g,j,n} Z_{jgqmnts} \le CPTY_q^{D-veh} \qquad \forall q,m,t,s \qquad (9)$$

$$\sum_{a'} Y_{pa'ats}^R \le 1 \qquad \forall p,a,t,s \qquad (10)$$

$$\sum_{n'} Y_{qn'nts}^D \le 1 \qquad \forall q,n,t,s \qquad (11)$$

$$\sum_{a'} Y_{pa'ats}^R = \sum_{a'} Y_{paa'ts}^R \qquad \forall p,a,t,s \qquad (12)$$

$$\sum_{n'} Y_{qn'nts}^D = \sum_{n'} Y_{qnn'ts}^D \qquad \forall q,n,t,s \qquad (13)$$

$$A_{pats} + (1 - Y_{pa'ats}^R) \times bigm \ge A_{pa'ts} + \omega T_{pa'a}^{sup} \qquad \forall p,a',a>1,t,s \qquad (14)$$

$$\xi + (1 - Y_{pa1ts}^R) \times bigm \ge A_{pats} + \omega T_{pma} \times Z_{pms}^R \qquad \forall p,m,a>1,t,s \qquad (15)$$

$$\alpha_{jqn'ts} + (1 - Y_{qn'nts}^D) \times bigm \ge \alpha_{jqnts} + Z_{jqmnts} \qquad \forall j,q,m,n',n>1,t,s \qquad (16)$$

$$\alpha_{jq1ts} \geq \sum_{n} Z_{jqmnts} \qquad \forall j,q,m,t,s \qquad (17)$$

$$Y_{pamts} \leq bigm \times \sum_{a'} Y^{R}_{pa'ats} \qquad \forall p,a,m,t,s \qquad (18)$$

$$Z_{jgqmnts} \leq bigm \times \sum_{n'} Y^{D}_{qn'nts} \qquad \forall j,g,q,m,n,t,s \qquad (19)$$

$$Y_{pamts} \leq bigm \times Z^{R}_{pms} \qquad \forall p,a,m,t,s \qquad (20)$$

$$Z_{jgqmnts} \leq bigm \times Z^{D}_{qms} \qquad \forall j,g,q,m,n,t,s \qquad (21)$$

$$Y_{pamts} \leq bigm \times X_{m} \qquad \forall p,a,m,t,s \qquad (22)$$

$$Z_{jgqmnts} \leq bigm \times X_{m} \qquad \forall j,g,q,m,n,t,s \qquad (23)$$

$$Z^{R}_{pms} \leq X^{R}_{ps} \qquad \forall p,m,s \qquad (24)$$

$$Z^{D}_{qms} \leq X^{D}_{qs} \qquad \forall q,m,s \qquad (25)$$

$$\sum_{p} Z^{R}_{pms} \leq bigm \times X_{m} \qquad \forall m,s \qquad (26)$$

$$\sum_{q} Z^{D}_{qms} \leq bigm \times X_{m} \qquad \forall m,s \qquad (27)$$

$$\sum_{m} Z^{R}_{pms} \leq 1 \qquad \forall p,s \qquad (28)$$

$$\sum_{m} Z^{D}_{qms} \leq 1 \qquad \forall q,s \qquad (29)$$

Constraints (1) and (2) have been used for considering the balance of the product inventory in the factory's warehouse. Constraint (3) computes the amount of milk used in each period for manufacturing the products. Constraint (4) ensures that the demand is met. Constraints (5) to (9) respectively guarantee that the capacities of the supplier, factory, milk-carrying vehicles, and product-carrying vehicles are not surpassed. Each vehicle visits each supplier and each retailer once in each time period. Constraints (10) and (11) are for the suppliers and retailers, respectively. According to constraint (12), if a vehicle enters a supplier center, it has to leave the center. Furthermore, if a vehicle visits a retailer, it has to leave the retailer as determined in constraint (13). Constraints (14) and (15) respectively guarantee that the sub tour is excluded and the sequence of the vehicles visiting the supplier is obtained. Moreover, constraint (16) has been employed to assure that the time window for the return of milk-carrying vehicles to the factory is not surpassed.

In addition, constraint (16) is the sub tour elimination constraint, while constraint (17) identifies the sequence of product-carrying vehicles in delivering the products to the retailers.

One of the conditions for collecting milk from the suppliers and delivering the products to the retailers is that the suppliers be visited by vehicles. The conditions for the suppliers and retailers are encompassed in constraints (18) and (19), respectively. Another condition for gathering milk from the suppliers and giving the products to the retailers is that the vehicles be assigned to the factories. This condition for milk-collecting and product delivery vehicles has been encompassed in constraints (20) and (21), respectively. If a factory is not operating, milk must not be delivered to it or its products must not be sent to the customers. This condition has been included in constraints (22) and (23), respectively. If a vehicle is not bought, it must not be assigned to the factory. This condition for milk-collecting vehicles and for delivery vehicles is encompassed in constraints (24) and (25), respectively. Another condition is that if a factory is not operating, no vehicle should be assigned to it. This condition for receiving milk and product delivery has been included in constraints (26) and (27), respectively. Each vehicle must be assigned to one distribution center at most. Constraint (28) has been considered for milk-collecting vehicles, whereas constraint (29) has been assumed for product delivery vehicles.

VI. Solution approach

i Modeling in the fresher first policy

In this policy, the fresher items exit the system earlier. To use this policy, additional variables and constraints must be added to the original model. For this purpose, the binary variable Ljgts is added to the problem. This variable takes the value of 1 when the items with age g are used to meet the demand of customer i in period t for scenario s for item n. The first set of equations limits the use of the variable Zjgqmnts. that is, using products with age g to meet the demands of the customers. This is done using the Ljgts variable as shown below.

$$\sum_n \sum_q \sum_m Z_{jgqmnts} \leq M \times L_{jgts}.\ \forall j.g.t.s(30)$$

The following constraint also shows that an older product is used after the fresher products have been used.

$$L_{jgts} \geq L_{jg+1ts}.\ \forall j.g.t.ss(31)$$

The following set of constraints is used to prevent the use of older products when fresher items still exist. Using the items with the age of g + 1 will be possible when the items with the age of 0 to g do not meet the demands. This constraint is written in the following way.

$$M(1 - L_{jg+1ts}) > \sum_m \sum_{w=0}^{g} ST_{jwmts} + \sum_m \lambda_{jmts} - \sum_n \left(demand_{jnts} \times \sum_{n'} Y^D_{qn'nts} \right) .\forall j.g.t.s(\mathbf{32})$$

ii Modeling in the older first policy

In this policy, the older items exit the system sooner. In order to use this policy, additional variables and constraints must be added to the original model. Similar to the fresher first policy, the binary variable Ljgtsis used in this policy. This variable takes the value of 1 when the items with age g are used to meet the demand of customer i in period t for scenario s for item n. The first set of equations limits the use of the variable Zjgqmnts, that is using the products with age g to meet the customer demands. This is done by using the Ljgts variable as shown below.

$$\sum_n \sum_q \sum_m Z_{jgqmnts} \leq M \times L_{jgts}.\ \forall j.g.t.ss(33)$$

The following constraint also demonstrates that a fresher product is used after the older products have been used.

$$L_{jgts} \leq L_{jg+1ts}.\ \forall j.g.t.ss(34)$$

The following set of constraints is employed to prevent the use of fresher products when older items are still available using items with age g-1 will be possible when the items with age g or more do not meet the demands. This constraint is written as follows.

$$M(1 - L_{jg-1ts}) > \sum_m \sum_{w=g}^{G} ST_{jwmts} + \sum_m \lambda_{jmts} - \sum_n \left(demand_{jnts} \times \sum_{n'} Y^D_{qn'nts} \right) .\forall j.g.t.s(\mathbf{35})$$

RESULTS

I. Data

The data for this model were presented by employing the evaluations of the experts at Sabah Company. Demand was considered as an uncertain parameter in the current study. The demand parameter depends on the number of retailers, the number of product variations, and time periods.

The problem has been solved using the sample average approximation method.

II. The Results of the Sample Average Approximation Method

The difference between these values has in practice been assumed to be the value of the stochastic solution (VSS). VSS is computed in the following way:

$$VSS = \bar{\bar{f}}_N(\bar{X}) - \bar{\bar{f}}_N(X^{MeanValue})$$

Where $\bar{\bar{f}}_N(\bar{X})$ is the middle value between the upper and lower bounds for the objective function which is acquired using the sample average approximation method for $\bar{X}$ and $\bar{\bar{f}}_N(X^{MeanValue})$ stands for the value of the objective function for the problem with the average parameter. Table 1 shows the comparative values for $\bar{X}^{1000}, \bar{X}^{2000}, \bar{X}^{3000}$, and $X^{MeanValue}$.

TABLE 1

THE VALUES OF THE OF THE STOCHASTIC MODEL SOLUTIONS

	$X^{MeanValue}$	$\bar{X}(M=150, N=100, N'=1000)$	$\bar{X}(M=150, N=200, N'=2000)$	$\bar{X}(M=150, N=300, N'=3000)$
OF	1,598,974,243	1,495,321,887	1,495,403,179	1,495,411,159
VSS	-	103,652,356	103,571,064	103,563,084

As can be seen in Table 1, by employing the stochastic model, the solutions were improved by about 6.92% in comparison with the model with average parameters.

III. Sensitivity Analysis of the Effect of Fuel Price on the Empty Capacity of the Vehicles

Figure 1 illustrates the behavior of the model for the different values of the coefficient of increase of fuel price (CIFP).

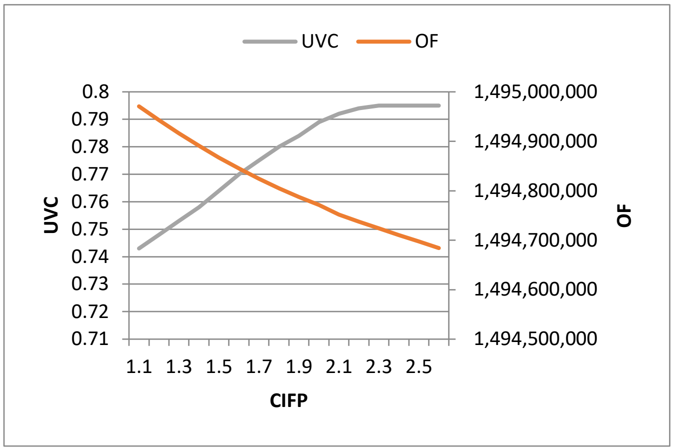

FIGURE 1
THE IMPACT OF FUEL PRICE ON UVC

IV. Sensitivity Analysis of the Effect of Reduced Product Price with the Increase of Age

Figure 2 illustrates the behavior of the objective function of the problem and the percentage of the perished products with decreased selling for different values of the coefficient of decrease of selling price (CDSP). It is obvious that as CDSP is enhanced, the value of the profit function is reduced. Put differently, as CDSP is enhanced the value of the perished product is also reduced. This behavior demonstrates that the percentage of the perished product (PPP) will enhance as profit margin is enhanced in a system producing perishable items.

V. Investigating the model using the fresher first and older first policies

It is obvious that different policies lead to different results. However, since the free policy imposes fewer constraints to the model than the fresher first and older first policies, it is expected to create a higher profit function compared with the other two policies. In the older first policy, since it is attempted to give the items that are older to the customers earlier than the other items, the number of the expired items is reduced. However, this leads to the lowest revenue. In the fresher first policy, since the fresher items are sold first and then the older items are sold, the number of the expired items increases along the decision-making horizon. Nevertheless, it generates more revenue for the decision maker than the older first policy. Table 2 summarizes these results.

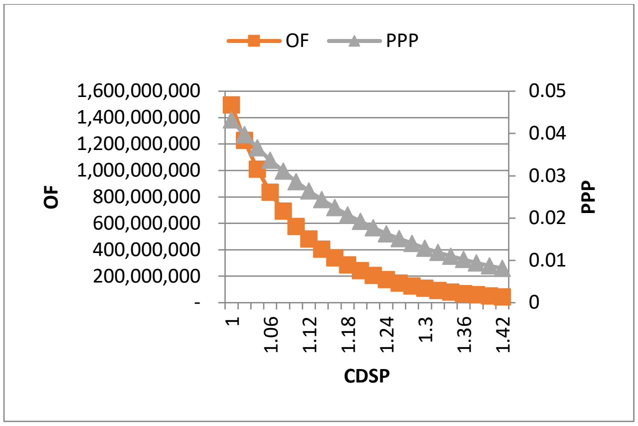

FIGURE 2
THE IMPACT OF CDSP ON PPP WITH THE INCREASE OF AGE

TABLE 2
THE RESULTS OF DIFFERENT POLICIES

	Inventory review policy		
	FP	FF	OF
The costs of supplying the items	4,499,361,690	4,667,637,817	4,428,721,711
The setup costs	2,238,060,898	2,282,822,115	2,256,812,853
The costs of the vehicles	264,248,950	269,529,878	266,704,847
The production costs	1,168,217,960	1,221,184,962	1,202,729,829
The holding costs	2,303,514	2,290,383	2,382,571
Revenue	9,667,561,953	9,893,976,253	9,544,522,892
Profit	1,495,368,941	1,450,511,098	1,378,171,081

CONCLUSION

In the current research, a three-level supply chain model for perishable products with different shelf lives was examined and the sales revenue and holding cost were calculated based on the shelf lives of the items. The production and distribution centers were able to deliver fresh or old items to the customers based on the fresher first, older first, or free policies. Nonetheless, the policy of the production and distribution centers was free. The production rate was sufficient to satisfy the customer demand. The presented model was applied in a two-stage structure. The decisions in the first stage led to the establishment of distribution centers, whereas the other variables were decided in the second stage. The results of these models demonstrated that among the older first, fresher first, free, and mixed policies, the free policy leads to more profits for the decision maker than the other three policies since it imposes fewer constraints on the model. In the older first policy, since the products with older shelf lives are delivered to the customers earlier than the other products, the number of the expired products is decreased. Nevertheless, they give the decision maker the least revenue. In the fresher first policy, because the fresher products are sold first and then the older products are sold, the number of the expired products is enhanced along the decision-making horizon. Nonetheless, the decision maker obtains a higher revenue compared to the older first policy.

REFERENCES

[1] Liu, G., Zhang, J., & Tang, W. (2015). Joint dynamic pricing and investment strategy for perishable foods with price-quality dependent demand. Annals of Operations Research, 226(1), 397-416.

[2] Shah, N. H. (2017). Three-layered integrated inventory model for deteriorating items with quadratic demand and two-level trade credit financing. International Journal of Systems Science: Operations & Logistics, 4(2), 85-91.

[3] Onggo, B. S., Panadero, J., Corlu, C. G., & Juan, A. A. (2019). Agri-food supply chains with stochastic demands: A multi-period inventory routing problem with perishable products. Simulation Modelling Practice and Theory, 97, 101970.

[4] Yang, P. C., & Wee, H. M. (2002). A single-vendor and multiple-buyers production–inventory policy for a deteriorating item. European Journal of Operational Research, 143(3), 570-581.

[5] Rau, H., Wu, M. Y., & Wee, H. M. (2003). Integrated inventory model for deteriorating items under a multi-echelon supply chain environment. International journal of production economics, 86(2), 155-168.

[6] Yavari, M., & Geraeli, M. (2019). Heuristic method for robust optimization model for green closed-loop supply chain network design of perishable goods. Journal of Cleaner Production, 226, 282-305.

[7] Seyedhosseini, S. and Ghoreyshi S (2014). An integrated model for production and distribution planning of perishable products with inventory and routing considerations. Mathematical Problems in Engineering, 2014 (10), 1-10.

[8] Yu, Y., Huang, G. Q., Hong, Z., & Zhang, X. (2011). An integrated pricing and deteriorating model and a hybrid algorithm for a VMI (vendor-managed-inventory) supply chain. IEEE Transactions on Automation Science and Engineering, 8(4), 673-682.

[9] Shaabani, H., &Kamalabadi, I. N. (2016). An efficient population-based simulated annealing algorithm for the multi-product multi-retailer perishable inventory routing problem. Computers & Industrial Engineering, 99, 189-201.

[10] Hsu, C. I., Hung, S. F., & Li, H. C. (2007). Vehicle routing problem with time-windows for perishable food delivery. Journal of food engineering, 80(2), 465-475.

[11] Seyedhosseini, S. M., MahdaviMazdeh, M., Makui, A., &Ghoreyshi, S. M. (2016). An inventory routing problem for perishable products with stochastic demands and direct deliveries. International Journal of Industrial Engineering & Production Research, 27(1), 21-30.

[12] Chao, C., Zhihui, T., &Baozhen, Y. (2019). Optimization of two-stage location–routing–inventory problem with time-windows in food distribution network. Annals of Operations Research, 273(1-2), 111-134.

[13] Khalili-Damghani, K., Abtahi, A. R., & Ghasemi, A. (2015). A new bi-objective location-routing problem for distribution of perishable products: evolutionary computation approach. Journal of Mathematical Modelling and Algorithms in Operations Research, 14(3), 287-312.

[14] S. Axs¨ater. *Inventory control*. International Series in Operations Research & Management Science, volume 90. Springer, New York, 2006.

[15] S. Nahmias. *Perishable Inventory Systems*. International Series in Operations Research & Management Science, volume 160. Springer, New York, 2011.

[16] R. Haijema. A new class of stock-level dependent ordering policies for perishables with a short maximum shelf life. *International Journal of Production Economics*, forthcoming, 2011.

[17] S. Minner and S. Transchel. Periodic review inventory-control for perishable products under service-level constraints. OR Spectrum, 32(4):979–996, 2010.

[18] Z. Karaesmen, A. Scheller-Wolf, and B. Deniz. Managing perishable and aging inventories: Review and future research directions. In K. G. Kempf, P. Keskinocak, and R. Uzsoy, editors, *Planning Production and Inventories in the Extended Enterprise*, volume 151 of *International Series in Operations Research & Management Science*, pages 393–436. Springer, New York, 2011.

[19] Nagurney, M. Yu, A. H. Masoumi, and L. S. Nagurney. *Networks against Time − Supply Chain Analytics for Perishable Products*. Springer, New York, 2013.

[20] H. Andersson, A. Hoff, M. Christiansen, G. Hasle, and A. Lǿkketangen. Industrial aspects and literature survey: Combined inventory management and routing. *Computers & Operations Research*, 37(9):1515–1536, 2010.

[21] L. C. Coelho, J.-F. Cordeau, and G. Laporte. Thirty years of inventory-routing. *Transportation Science*, forthcoming, 2014. doi: 10.1287/trsc.2013.0472.

[22] Leandro C. Coelho, Gilbert Laporte. (2014). Optimal Joint Replenishment, Delivery and Inventory Management Policies for Perishable Products, Computers & Operations Research, 47, 42–52.

[23] Axsäter, S. (2006). Planning order releases for an assembly system with random operation times. In *Stochastic Modeling of Manufacturing Systems* (pp. 333-344). Springer, Berlin, Heidelberg.

[24] Raafat, F., Wolfe, P. M., & Eddin, H. K. (1991). An inventory model for deteriorating items. Computers and Industrial Engineering, 20(1), 89-94.

[25] Moghaddam, S. T., Javadi, M., & Molana, S. M. H. (2019). A reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization. Journal of Industrial Engineering International, 15(4), 709-721.

[26] Panda, G. C., Khan, M. A. A., & Shaikh, A. A. (2019). A credit policy approach in a two-warehouse inventory model for deteriorating items with price-and stock-dependent demand under partial backlogging. Journal of Industrial Engineering International, 15(1), 147-170.

[27] Abou Chakra, H., & Ashi, A. (2019). Comparative analysis of design/build and design/bid/build project delivery systems in Lebanon. Journal of Industrial Engineering International, 15(1), 147-152.

[28] Saeidi, R.G., Amin, G.R., Raissi, S. et al. An efficient DEA method for ranking woven fabric defects in textile manufacturing. Int J Adv Manuf Technol 68, 349–354 (2013). https://doi.org/10.1007/s00170-013-4732-4