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# Simultaneous Pricing, Routing, and Inventory Control for Perishable Goods in a Two-echelon Supply Chain

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A B S T R A C T

Due to the rapid development of technology in recent years, market competition and customer expectations have increased more than ever. In this situation, it is vital for businesses survival to determine the appropriate policy for inventory control, pricing, and routing, and decisions regarding each of them are often made separately. If the products have a perishable nature, it will be more important to determ ine the above policies. For integration of the decision-making concerning the three key components of the supply chain ,i.e. pricing, routing, and inventory control, two mathematical models were developed for a two-echelon supply chain of perishable items with direct shipment, where fixed lifetime is assumed in one model and random lifetime in another, so that profit is maximized. The proposed mathematical model was solved using the CPLEX solver package of the GAMS software for specification of the optimal policy of the supply chain. The results demonstrated that the CPU time needed for solving the mathematical model for perishable items with random lifetime was less than that for fixed lifetime, while the value of the objective function for products with fixed lifetime was greater than that for products with random lifetime.

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## 1. INTRODUCTION

The problem of inventory-routing and perishable goods pricing consists of two important problems: inventory-routing and pricing.

The inventory-routing problem is an important extension of the vehicle routing problem, where inventory control and routing policies are determined simultaneously [1]. The inventory-routing problem is used in vendor-managed inventory systems. In such systems, the vendor is able to control the time and size of product delivery to the retailers. Instead, the vendor guarantees that shortage will not occur. However, in the traditional approach, where customers ordered products, efficiency might be reduced greatly, and inventory control and distribution costs might be increased as a result of the time-consuming processing of customers' orders. Nevertheless, it is not easy in practice to reduce the costs of utilizing vendor-managed inventory systems, and it is especially difficult when the number and variety of customers increase. The inventory-routing problem can be used for this purpose [2].

Pricing decisions simultaneously affect demand and inventory and routing decisions. For maximum of profit in the supply chain, for example, higher prices lead to less demand, and reduce the amounts of order and inventory. In contrast, lower prices lead to increase demand, and increase the amounts of order and inventory. On the other hand, pricing decisions depend on inventory-routing decisions. Profit may be reduced when these are considered separately. Therefore, it is a very important issue in supply chain management how inventory control, routing, and pricing policies are determined simultaneously [3].

Given that the present study determines inventory control, routing, and pricing policies for perishable products; it is essential to review the concept of perishability in the literature. In general, any product that loses its value over time is called perishable. Based on this definition, vegetables, fruits, and drugs can be considered as perishable goods [4].

Perishable goods are divided into two categories [5]:

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Category I) goods such as food, fresh vegetables, human blood, and photographic films that have fixed lifetime for use, called perishable goods with fixed lifetime;
Category II) goods such as alcohol, gasoline, and radioactive materials that have no allowable shelf-life, called decaying goods with random lifetime.

In this study, both categories, i.e. perishable goods with fixed lifetime and with random lifetime, are investigated. The reminder of the paper is organized as follows. After a brief review of the literature, the inventory-routing and pricing problems are described in section two. The mixed-integer mathematical model and thes pecified assumptions are presented in sections three and four. Section five is dedicated to the computational results. Finally, the conclusion of the study and directions for future research are described in section six.

## 2. LITERATURE REVIEW

Given that the problem under investigationconsists of the three different domains of routing, inventory control, and pricing, the literature on inventory-routing, pricing-inventory, routing-inventory, and pricing for perishable goods is simultaneously studied.

In previous studies, researchers have classified inventory-routing problems considering different factors. Kleywegt et al. [6] classified research in the field of routing-inventory based on four criteria of demand (definite, probable), transportation fleet capacity (limited, unlimited), planning horizon (short-term, long-term, decreased), and delivery type (multiple, direct).

Campbell and Savelsbergh [7] investigated on routing-inventory problem followed one of three lines listed below:
A) one-day modeling using deterministic or stochastic demand;
B) short-term modeling using deterministic or stochastic demand;
C) permanent routes usually with long-term planning purposes.

Andersson et al. [8] considered seven criteria for the routing-inventory problem that include time (moment, limited, unlimited), demand (definite, probable), topology (one-to-one, one-to-many, many-to-many), routing (straight, multiple, continuous), inventory (fixed, shortages, lost sales, backlog), transportation fleet (identical, fraternal), and fleet size (single vehicle, multiple vehicles, unlimited). Noor and Shuib [9] also studied the routing-inventory problem based on eight criteria including time (limited, unlimited), topology (one-to-one, one-to-many, many-to-many), routing (direct, multiple), product number (single commodity, multiple commodities), inventory policy (maximum level (ML), order up to level (OU)), shortage (lost sales, backlog), transportation fleet composition (identical, fraternal), and fleet size (single vehicle, multiple vehicles, unlimited). Table 1 summarizes the studies on the routing-inventory problem making various assumptions such as deterministic or non-deterministic demand, type of routing problem, and inventory control policies. Pricing and inventory control of perishable goods has been studied by many researchers.

Yang et al. [10] proposed an inventory control and pricing model for perishable goods with fixed lifetime. Mo et al. [11] studied inventory control and pricing models with a price-dependent, inventory-level demand. Tsu et al. [12] considered a model similar to that in Mo et al. [11], differenct in that the inventory-based demand function was available and reduced over time to zero. Geetha and Otayakomar [13] presented a model to determine the economic order quantity for perishable goods with fixed lifetime assuming that the delay in payment is authorized. Mihami and Nakhai [14] presented a pricing and inventory control model for perishable goods with fixed lifetime, in which demand was assumed to be based on price and time, and slight shortage was allowed. Zhang et al. [15] provided a model aimed at increasing total profit at any time by determining the optimal sales price assuming price-dependent demand, an unlimited time horizon, and disallowed shortage. Qin et al. [16] offered a model for inventory control and pricing of perishable goods assuming an infinite replenishment rate, zero waiting time, unauthorized shortage, an infinite time horizon, a corruption rate with variable lifetime, and inventory- and price-dependent demand. Rabbani et al. [17] proposed a model for inventory pricing with a replenishment rate, corruption involving physical quantity and quality with quality corruption rates at all times of a bivariate Weibull distribution and a physical quantity corruption rate at any time of a three-parameter Weibull distribution, an unlimited planning horizon, an unlimited replenishment rate, zero waiting time, unauthorized shortage, and demand as a function of the sales price. Lin and Wu [18] proposed an experimental inventory and pricing model in a three-echelon supply chain in the shrimp industry in Taiwan, and introduced a competitive market with potential demand.

There have been a few studies in the area of integrating the inventory-routing and pricing problems. Liu and Chen [3] proposed a model for a two-echelon supply chain with one supplier and several retailers, in which all the retailers are located in a single geographical area, and several similar vehicles with the same capacity are used. The problem is single-product with typical goods, where each retailer is provided a vehicle, and the total demand on each route must be less than or equal to the capacity of the vehicle, and each route starts and ends with a supplier. The costs of loading and unloading as well as those of inventory ordering and holding for suppliers are ignored, and demand is a linear function with values within a certain range from minimum to maximum demand for every retailer. Hasanvand and Sohrabi [19] also proposed.

A model considering a two-echelon supply chain involving several suppliers and several retailers, where all retailers are located in a single geographical area. The problem is single-product with typical goods, where any retailer's demand is a linear function that can be met by any of the providers, and transportation and maintenance costs are simultaneously considered as well as acquisition costs for retailers. Taleizadeh et al. [20] proposed an economic production quantity (EPQ) model for reworkable defective items. Due to the high complexity of the mathematical model, a heuristic approach was developed to obtain the optimal values of manufacturing lot size and price.

For a comprehensive discussion on inventory models such as economic order quantity, supply chain inventory models, inventory models with trade credits, and periodic and continuous inventory models, the study was conducted by Cárdenas-Barrón et al. [21]. Two markets with different levels of willingness were considered by Taleizadeh et al. [22]. There are manufacturers in both of these markets, which offer the same product at different prices according to the willingness of each market to pay. In the market with lower willingness to pay, the manufacturer's product is purchased not only by a group of customers but also by the parallel importer who later attempts to sell the product in the market with higher willingness to pay. Moreover, in the market with lower willingness to pay, the manufacturer competes with another manufacturer that offers a similar product. A two-echelon supply chain system was considered by Fattahi et al. [23], in which a supplier produces a perishable product, and distributes it to multiple customers.

A reverse supply chain was considered by Moubed and Mehrjerdi [24], and a hybrid programming approach was developed for solving the mathematical model of the problem. Setak and Daneshfar [25] proposed an inventory model for deterioration of products. They considered a two-echelon supply chain managed under the VMI policy.

## 3. ASSUMPTIONS

The problem under study in this paper is modeled based on the following assumptions.

The assumptions proposed for perishable goods with fixed lifetime follow:

1) Comprises one manufacturer and several retailers, where a vendor-managed inventory system is in operation.

2) The problem is multi-product with deterministic demand and the objective of maximizing the profits of the supply chain members. The products are perishable, and have fixed lifetime (e.g., blood and medicine).

3) The storage capacity of the manufacturer and the retailers is limited, and no stock-out is allowed.

4) The manufacturer's capacity is limited, and is known in advance for each production period.

5) The products are distributed among the retailers using vehicles with limited capacity and under the strategy of direct delivery.

Inventory and pricing problem, the models presented by Liu and Chen [3], Mirzaei et al. [2], Nachiappan and Jawaher [26], Hamelmayer et al. [27], and Le et al. [28]; which were taken as the bases for the idea. Before the model is presented, the information required in the objective function is discussed.

A. Income function

The demand function of a product is defined as the relationship between demand quantity and price.

$$p_j = a_j - b_j \times y_j \quad (1)$$

The demand of the retailer in Constraint (2) is j in planning period t.

$$y_j = d_{jt} \quad (2)$$

By substituting Constraint (2) in Constraint (1), we have:

$$p_j = a_{jt} - b_j \times d_{jt} \quad (3)$$

Moreover, the retailer's income is calculated using Constraint (4) as follows:

$$p_j \times q_j = a_j \times d_{jt} - b_j \times d_{jt}^2 \quad (4)$$

For several products and several retailers, the income function is:

$$\sum_{t=1}^{T} \sum_{j=1}^{N} \sum_{p=1}^{K} (a_{pj} \times d_{pjt} - b_{pjt} \times d_{pjt}^2 \quad (5)$$

B. Supply chain costs

The cost of setting up production in period t is:

$$\sum_{t=1}^{T} f_t \times y_t \quad (6)$$

The cost of transporting product p from node j to retailer i is:

$$\sum_{t=1}^{T} \sum_{j=1}^{N} \sum_{p=1}^{K} c_{ij} \times z_{ijt} \quad (7)$$

The cost of holding the inventory of product type p in retailer i is:

$$\sum_{t=1}^{T} \sum_{j=1}^{N} \sum_{p=1}^{K} h_{pjt} \times I_{pjt} \quad (8)$$

C. Product corruption costs (perishable goods with variable lifetime)

The cost of lost quality is:

$$\sum_{t=S_P}^{T} \sum_{j=0}^{N} \sum_{p=1}^{K} L_p \times I_{pjt} \quad (9)$$

**TABLE 1.** Classification of the studies on the routing-inventory problem for perishable goods

| Topology | Product number | Demand | Time | Fleet size | Transportation fleet composition | Routing | Inventory policy | Shortage | Reference |
|---|---|---|---|---|---|---|---|---|---|
| One-to-many | multiple commodities | deterministic | Limited | Few | Identical | Multiple | ML | Lost sales | Popović et al. [29] |
| One-to-many | single commodity | deterministic | Limited | Decision Variable | Identical | Direct | - | Unauthorized | Le et al. [28] |
| One-to-many | single commodity | - | Limited | Unlimited | Identical | Multiple | ML | Unauthorized | Li et al. [30] |
| One-to-many | multiple commodities | deterministic | Limited | Few | Identical | Direct | - | Unauthorized | Vidović et al. [31] |
| One-to-many | single commodity | - | Unlimited | Unlimited | Identical | Multiple | - | Unauthorized | Aksen et al. [32] |
| Many-to-many | single commodity | stochastic | Limited | One | - | Multiple | - | Unauthorized | Singh et al. [33] |
| One-to-many | single commodity | deterministic | Limited | Unlimited | Identical | Multiple | ML | Lost sales | Mirzaei and Seifi [34] |
| Many-to-many | multiple commodities | stochastic | Limited | Unlimited | Identical | Multiple | - | Backlog | Soysal et al. [35] |
| One-to-many | multiple commodities | deterministic | Limited | Unlimited | Identical | Multiple | - | Unauthorized | Shaabani and Kamalabadi [36] |

The mathematical model for perishable goods with fixed lifetime under the strategy of direct shipment is formulated as a mixed integer programming model, using Constraints (10) to (18).

$$\max z = \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{p=1}^{K}(a_{pj}\times d_{pjt} - b_{pjt}\times d_{pjt}^{2}) - \sum_{t=1}^{T} f_t \times y_t - \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{i=1}^{N} c_{ij}\times z_{ijt} - \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{i=1}^{N} h_{pjt}\times I_{pjt}, \quad (10)$$

$$I_{pj(t-1)} + w_{pjt} - I_{pjt} = d_{pjt} \qquad \forall p, j | j\neq 0, t \qquad (11)$$

$$I_{p0(t-1)} + P_{pt} - I_{p0t} = \sum_{j=1}^{N} w_{pjt} \qquad \forall p, t \qquad (12)$$

$$\sum_{p=1}^{k} \beta_p \times P_{pt} \le P_{\max}^{t} \times y_t \qquad \forall j, t \qquad (13)$$

$$\sum_{p=1}^{k} \alpha_p \times I_{pjt} \le I_{\max}^{j} \qquad \forall t \qquad (14)$$

$$\sum_{p=1}^{k} \alpha_p \times w_{pjt} \le Q \times z_{ijt} \qquad \forall i, j | j\neq 0, t \qquad (15)$$

$$I_{pjt} \le \sum_{s=t}^{t-L_{\max}^{p}-1} d_{pjs} \qquad \forall p, j, t \qquad (16)$$

$$z_{ijt}, y_t \in \{0,1\} \qquad \forall i, j, t \qquad (17)$$

$$I_{pjt}, w_{pjt}, P_{pt} \ge 0 \qquad \forall p, j, t \qquad (18)$$

Constraint (10) indicates the objective function of the proposed model,which includes the incomes of the supply chain members, constant startup costs, costs of sending the product to the retailers, product maintenance costs by the producers and retailers. The inventory flow balance equations for the retailers and manufacturer are guaranteed by Constraints (11) and (12) respectively. Constraint (13) ensures that production capacity is not exceeded. Constraint (14) represents the storage capacity of the manufacturer and retailers. Constraints (13) and (14) implicitly indicate whether the manufacturer has produced products, or a product has been sent to retailer i in period t. Limited transport capacity is shown using Constraint (15). Constraint (16) ensures that the perishable products will never be spoiled: i.e. total demand $L_{max}^{p}$ units of time after the beginning of period t will be greater than or at least equal to inventory level at the beginning of period t. Hence, no spoilage will occur, since no inventory remains on hand. The technical constraints on the decision variables are realized by Constraints (17) and (18).

The mathematical model for perishable items with random lifetime under the strategy of direct shipment is formulated as a mixed integer programming model, using Constraints (19) to (26).

$$\max z = \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{p=1}^{K}(a_{pj} \times d_{pjt} - b_{pjt} \times d_{pjt}^{2}) - \sum_{t=1}^{T} f_t \times y_t - \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{i=1}^{N} c_{ij} \times z_{ijt} - \sum_{t=1}^{T}\sum_{j=1}^{N}\sum_{i=1}^{N} h_{pjt} \times I_{pjt} - \sum_{t=S_p}^{T}\sum_{j=0}^{N}\sum_{p=1}^{K} L_p \times I_{pjt} \quad (19)$$

$$I_{pj(t-1)} + w_{pjt} - I_{pjt} = d_{pjt} \qquad \forall p, j \mid j \neq 0, t \quad (20)$$

$$I_{p0(t-1)} + P_{pt} - I_{p0t} = \sum_{j=1}^{N} w_{pjt} \qquad \forall p, t \quad (21)$$

$$\sum_{p=1}^{k} \beta_p \times P_{pt} \leq P_{\max}^{t} \times y_t \qquad \forall j, t \quad (22)$$

$$\sum_{p=1}^{k} \alpha_p \times I_{pjt} \leq I_{\max}^{j} \qquad \forall t \quad (23)$$

$$\sum_{p=1}^{k} \alpha_p \times w_{pjt} \leq Q \times z_{ijt} \qquad \forall i, j \mid j \neq 0, t \quad (24)$$

$$z_{ijt}, y_t \in \{0,1\} \qquad \forall i, j, t \quad (25)$$

$$I_{pjt}, w_{pjt}, P_{pt} \geq 0 \qquad \forall p, j, t \quad (26)$$

Constraint (19) indicates the objective function of the proposed model,which includes the incomes of the supply chain members, constant startup costs, shipment costs of the product to the retailers, product maintenance costs by the producers and retailers, and costs of lost quality. The inventory flow balance equations for the retailers and manufacturer are guaranteed by Constraints (20) and (21), respectively. Constraint (22) ensures that production capacity is not exceeded. Constraint (23) represents the storage capacity of the manufacturer and retailers. Constraints (22) and (23) implicitly indicate whether the manufacturer has produced products, or a product has been sent to retailer j in period t. Limited transport capacity is shown using Constraint (24). The technical constraints on the decision variables are realized by Constraints (25) and (26).

## 4. COMPUTATIONAL EXPERIMENTS

The performance of the proposed model is discussedusing random sample problems. The proposed model is programmed in the GAMS24.1.3 environment, and implemented using the CPLEX solver. All the obtained results were implemented on a computer with an Intel(R) processor, 3.10 GHz, Windows 7, and 4 GB of RAM.

**4. 1. Test problems** Because there is no benchmark data set available for this study, we generate a number of random test problems in three groups: small, medium, and large. The sizes of the problems and planning periods, number of retailers, and number of products are shown in Table 5.

In this study, the structure of the sample problems is considered to be similar to that in reference [37]. Given that the producer is located at the origin of the coordinate system, the retailers are uniformly distributed on a square with sides of 100 units. Therefore, $c_{ij}$ is the product of the Euclidean distances between the producers and retailers in the unit of currency. In this paper, as in literatures [2, 37], production and vehicle capacity are considered based on demand and fixed production setup cost, and manufacturer warehouse capacity is in accordance with manufacturing capacity. The retailers' storage capacity is proportional to that of the vehicles. Specifically, the capacity of the vehicles is 2 times the average demand of a retailer, and production capacity is 3.5 times the average daily demand of all the retailers. Fixed production cost is 1.5 times maximum production capacity in different periods, and the manufacturer's storage capacity is equal to maximum production capacity. All the retailers' storage capacity is the same and equal to the specified vehicle capacity. In Table 6, $d_p$ indicates the average demand of product p for all the retailers in one period.

In generation of sample problems with 5 products, five different levels of demand, including very low ($d_{1jt}$), low ($d_{2jt}$), average ($d_{3jt}$), high ($d_{4jt}$), and very high ($d_{5jt}$) demand, are taken into account, and the demand for any product in any period is created uniformly in the range presented in Table 6.

**TABLE 5.** Problem instances

| Problem No. | Dimension (T×N×P) | Problem No. | Dimension (T×N×P) |
|---|---|---|---|
| 1 | Small(10*5*3) | 11 | Medium(10*30*5) |
| 2 | Small(15*5*3) | 12 | Medium(15*30*5) |
| 3 | Small(10*5*5) | 13 | Large (10*100*3) |
| 4 | Small(10*10*3) | 14 | Large (10*120*3) |
| 5 | Small(15*5*5) | 15 | Large (15*100*3) |
| 6 | Small(15*10*3) | 16 | Large (10*100*5) |
| 7 | Small(10*10*5) | 17 | Large (15*120*3) |
| 8 | Small(15*10*5) | 18 | Large (10*120*5) |
| 9 | Medium(10*30*3) | 19 | Large (15*100*5) |
| 10 | Medium(15*30*3) | 20 | Large (15*120*5) |

For problems with three products, three levels are considered: very low ($d_{1jt}$), average ($d_{3jt}$), and very high ($d_{5jt}$) demand.

The maximum time allowed for maintenance of each product is considered to be proportional to the number of planning periods. The time required for starting the quality change of each product with variable lifetime is like the maximum time allowed for maintenance of any product. The cost of lost quality is uniformly considered as discrete between 3 and 8. The fixed value of product *p* in the demand function of retailer *j* is uniformly considered as discrete between 180 and 210, and the slope of the demand function of product *p* for retailer *j* in period t is uniformly considered between 0.03 and 0.08.

**4. 2. Numerical Results** Each sample problem is solved using the CPLEX solver, and the results for perishable products with fixed lifetime are presented in Table 7 and those for perishable goods with random lifetime in Table 8.

As can be seen in Tables 7 and 8, different problems of even large scales are solvable in reasonable time, and can obtain the optimal solutions.

Comparison of Tables 7 and 8 demonstrates that when product lifetime is fixed, the CPU time needed for solving the problem increases, and it is time-consuming to find the optimal values. Therefore, we believe that, meta-heuristic approaches are the best choice for mathematical models with fixed lifetime. A comparison between the objective function values of the two proposed mathematical models is shown in Figure 1.

In light of the results of the mathematical models, it seams that investment on products with fixed lifetime may lead to high profits for supply chain members.

**TABLE 6.** Values of the parameters

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $d_{1jt}$ | U[1,3] | $Q$ | $2\sum_p a_p \times d_p$ |
| $d_{2jt}$ | U[7,10] | $P_{max}$ | $3.5N\sum_p k_p \times d_p$ |
| $d_{3jt}$ | U[15,20] | $f_t$ | $1.5P_{max}$ |
| $d_{4jt}$ | U[25,35] | $I_{max0}$ | $Max(P_{max})$ |
| $d_{5jt}$ | U[45,60] | $I_{maxj}$ | $Q$ |
| $\alpha_p$ | 1 | $h_{pj}$ | 1 |
| $\beta_p$ | 1 | $O_p$ | DU[3,8] |
| $L^p_{max}$ $S_p$ | 2 or 3 | $a_{pj}$ | U[180,210] |
| | | $b_{pjt}$ | U[0.03,0.08] |

**TABLE 7.** Summary of the computational results for fixed lifetime

| Problem No. | Objective function | Time (s) | Problem No. | Objective function | Time (s) |
|---|---|---|---|---|---|
| 1 | 800882.84 | 1.03 | 11 | 6412383.21 | 24.27 |
| 2 | 1184407.28 | 3.22 | 12 | 9602565.73 | 95.07 |
| 3 | 1313823.77 | 1.07 | 13 | 13502241.23 | 535.20 |
| 4 | 1475791.28 | 1.75 | 14 | 16268633.84 | 711.61 |
| 5 | 1879359.36 | 3.81 | 15 | 20114704.91 | 458.88 |
| 6 | 2190031.06 | 6.81 | 16 | 20899961.11 | 1812.52 |
| 7 | 2277393.69 | 3.30 | 17 | 24047843.31 | 1907.69 |
| 8 | 3396867.76 | 51.08 | 18 | 25046418.70 | 509.19 |
| 9 | 4190742.05 | 7.80 | 19 | 31226338.64 | 3657.02 |
| 10 | 6203215.19 | 22.67 | 20 | 37636346.11 | 4809.25 |

**TABLE 8.** Summary of the computational results for random lifetime

| Problem No. | Objective function | Time (s) | Problem No. | Objective function | Time (s) |
|---|---|---|---|---|---|
| 1 | 799275.54 | 1.03 | 11 | 6381751.70 | 11.22 |
| 2 | 1185314.18 | 1.19 | 12 | 9506614.22 | 12.55 |
| 3 | 1250109.14 | 1.05 | 13 | 13412404.50 | 310.45 |
| 4 | 1453144.26 | 1.45 | 14 | 16092503.93 | 684.06 |
| 5 | 1836779.93 | 1.19 | 15 | 19912030.92 | 579.66 |
| 6 | 2181925.25 | 3.97 | 16 | 20675919.14 | 12.06 |
| 7 | 2242095.56 | 1.83 | 17 | 23915678.93 | 1435.42 |
| 8 | 3349799.58 | 1.39 | 18 | 24865894.72 | 71.75 |
| 9 | 4114797.57 | 8.89 | 19 | 30962949.81 | 267.42 |
| 10 | 6105863.12 | 33.91 | 20 | 37132451.78 | 194.56 |

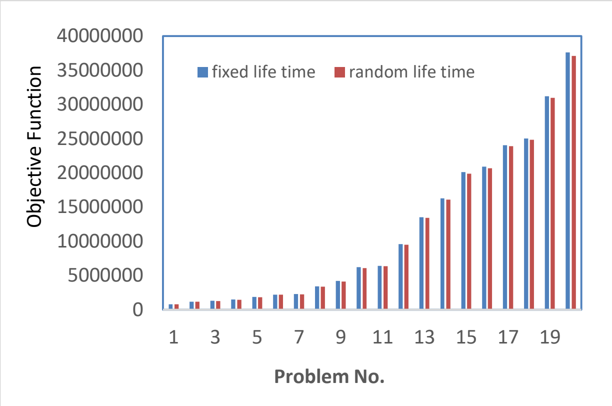


**Figure 1.** A comparison between the objective function values of the two mathematical models

## 6. CONCLUSIONS AND DIRECTIONS FOR FUTURE

The study was dedicated to a multi-period multi-product inventory-routing problem concerning perishable items. It was assumed that several perishable products were produced in a company and sent to a group of retailers via direct delivery using a fleet of transportation vehicles with limited capacity. Furthermore, any retailer should be given service in each period only through one means of transportation and once. The inventory capacity of both the producers and retailers was limited, the manufacturers had limited production capacity, and shortage was not allowed. The proposed mathematical model was solved by the CPLEX solver of the GAMS software to obtain the optimal solution, and several numerical examples with different dimensions were solved for demonstrating the reliability and efficiency of the model. The results indicated that the CPU time needed for solving the mathematical model for perishable items with random lifetime was less than that for fixed lifetime, while the values of the objective functions for both models were apparently similar.

As a direction for future research, extension of the above-mentioned problem to other conditions that may exist in the real world can be considered. Therefore, it is suggested that the problem be extended to conditionswhere shortage is allowed, or several deliveries or delivery through several routes is possible for a retailer in any period. Investigation of the reverse logistics and vehicle scheduling could be other interesting topics for future research.

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# Simultaneous Pricing, Routing, and Inventory Control for Perishable Goods in a Two-echelon Supply Chain


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**چکیده**


طی سال‌های اخیر به دلیل پیشرفت سریع تکنولوژی، رقابت در بازار و سطح انتظارات مشتریان بیش از پیش افزایش یافته‌است. در چنین شرایطی تعیین سیاست مناسب کنترل‌موجودی، قیمت‌گذاری و مسیریابی، امری حیاتی برای بقاء بنگاه‌های اقتصادی محسوب می‌شود که اغلب بطور جداگانه در مورد آنها تصمیم‌گیری می‌شود. در صورتی‌که کالای مورد نظر فسادپذیر باشد تعیین سیاست‌های عنوان شده از اهمیت بالاتری برخوردار خواهد بود؛ از این‌رو در این تحقیق به منظور یکپارچه‌سازی تصمیم‌گیری در خصوص سه مولفهٔ کلیدی زنجیره‌تأمین شامل قیمت‌گذاری، مسیریابی و کنترل‌موجودی، دو مدل ریاضی با هدف بیشینه نمودن سود برای زنجیره‌تأمین دوسطحی اقلام فسادپذیر در دو حالت طول عمر ثابت و متغیر با در نظر گرفتن استراتژی ارسال مستقیم، توسعه داده شده و سپس با استفاده از بسته نرم افزاری *CPLEX* در محیط *GAMS* به منظور تعیین سیاست بهینه زنجیره‌تأمین حل خواهد شد. نتایج محاسباتی نشان میدهد که زمان حل مدل ریاضی برای اقلامی که طول عمر آنها متغیر است در مقایسه با مدل ریاضی دیگر، بسیار کمتر است ضمن اینکه سود حاصل از اقلامی که دارای طول عمر ثابت هستند بیشتر از سود حاصل از اقلام با طول عمر تصادفی است.


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