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Vendor managed inventory policy for perishable products under a combination of FIFO-LIFO stock control

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ABSTRACT For retailing systems, arranging the perishable products has always been a challenge. Although more profit is made when products are sold with a FIFO policy, now customers taste in a competitive market which requires new products to be offered to them has changed the game. This paper considers a hybrid of FIFO-LIFO strategies for controlling a retailer's stock and its impact on the profits of the vendor managed inventory contracts. The problem is formulated as a multi-period, multi-store integer programming model which aims to maximize the total profit. The proposed model considers different selling prices and different holding costs for perishable products according to their remaining shelf life. A dynamic programming with a backward strategy is proposed to find the optimal order quantity for each store. The numerical experiments confirm the applicability and efficiency of the model illustrating impact of the crucial parameters of the model on the stocking policy.

KEYWORDS Food processing; Optimal policy; Consumption; Dynamic programming; Shelf life

1. Introduction

There are some practices that allow us to improve the exchange of information between suppliers and customers in order to better relate demand to supply, such as Continuous Replenishment Planning (CRP) and Vendor Managed Inventory (VMI) (Júnior et al., 2005). The VMI approach relies on cooperation and information sharing among supply chain members. When VMI is implemented, the supplier takes over the responsibility of managing the customers' inventory by deciding on replenishment quantities and delivery periods. Thus, in VMI, the vendor has access to the customer's data and himself takes the decisions of refueling (Disney et al., 2003). The VMI can improve the supply chain performance by reducing inventory levels and increasing the replenishment rates (Gani and Sabarinathan, 2013).

Garrone et al. (2014) have improved the agile supply chain performance where retailer shares its own customer's demand and inventory position data to the vendor, to make the appropriate decisions on the order size. Applying a proper design in the vendor managed inventory strategy decreases the inventory costs, response time to customer demands, and enhances a good collaboration at the different levels of the chain.

Distribution as an important part of supply chain network design is characterized by the vendor managed inventory contract (As'ad et al., 2019; Polotski et al., 2017). The main motivation is to integrate the distribution network with the vendor managed inventory model for perishable products. One of the reasons is that managing supply chains of perishable products is significantly more complex than managing supply chains of durables and non-perishable products (Transchel and Hansen, 2019). In VMI supply chain vendor is responsible to inventory management. Clearly the vendor controls inventory level of retailers based on service level agreements, so it can be an efficient way to manage the inventory of perishable products (Akbari Kaasgari et al., 2017). The fact that these types of products only have a limited lifetime and that may face quality changes once they become older; the age of the inventory plays a critical role in production and inventory planning.

The state of such perishable product inventory systems can be completely specified by the quantities of stock of different ages on hand and on order. Any analysis, therefore, of the inventory behavior in such systems must incorporate explicit assumptions concerning the sequence in which stock items of different age, present in the inventory, are issued to meet demand.

The issuing sequence rules observed most often in practice are FIFO (First-In-First-Out) and LIFO (Last –In-First-Out). The FIFO rule chooses the oldest available item first, and is issuing policy preferred by most managers. LIFO, on the other hand, issues youngest stock first and is observed in situations where the consumer has control of decision(Cohen and Prastacos, 1981).

In most perishable inventory models either the FIFO or the LIFO issue policy is possible, although in there al-world (for example in grocery retail) a mix of both policies is commonly used. Thus, more future models could be developed in which both issue policies are considered together (Janssen et al., 2016). In this area, Hemmati and Afshar-Nadjafi (2017) presented an EPQ model with processing for deteriorating products. Also, Momeni and Afshar-Nadjafi (2020) addressed a processing system with multiple products, single-vendor and single-buyer is considered to maximize the inventory system's profit.

One significant source of food waste at retailers and in households seems to be the un-willingness to sell, pur-

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chase, or consume suboptimal or imperfect foods (Buzby and Hyman, 2012). Food waste is generated in immense amounts across the food life cycle, imposing serious environmental, social and economic consequences. Although consumers are the single biggest contributor to this volume, little is known about the drivers of food waste in house-holds. This exploratory study aims to investigate the role of food choices and other food-related activities in producing food waste (Stefan et al., 2013). The presence of food waste, and ways to reduce food waste, has generated significant debate among industry stakeholders, policy makers, and consumer groups. Food Waste Challenge, an initiative to reduce food waste throughout the food supply chain (Wilson et al., 2017).

Studies find that the majority of food waste at the retail stage is linked to expiration date. In expiration date based pricing, the food item nearing its expiration date is still located in the store. Therefore, its 'degree of recoverability' is high, as intrinsic recoverability (the quality inherent to the product) is high and management intensity of recovery is low (Garrone et al., 2014). Consumer acceptance of expiration date based pricing of suboptimal food can be increased through furthering consumer familiarity with the practice, improving perceived quality and providing tips to ensure consumers are confident to be able to use the entire food at home (Aschemann-Witzel, 2018).

A two-stage stochastic programming model of a production routing problem for a perishable product with a short shelf life was developed to optimize the total costs of wasted products, non-fresh products, production, inventory, and routing. To take into account the freshness level of products and the amount of wasted products, the model was formulated based on decision variables that are related to the age of products (Mousavi et al., 2022).

A hybrid dynamic discrete-time inventory model with random lifetime perishable products was developed by Chołodowicz and Orłowski (2021), issuing the policies of first in–first out (FIFO) and last in-first out (LIFO) in positive lead time and time-dependent demand such as closing days. The vendor is a manufacturer in charge of making decisions to determine the order size and number of shipments (Safaeian et al., 2019). To identify the contributions of the proposed model and to distinguish it from the previous works, several extensions have been added. In the real problem, the proportion of perishable products with regards to the fresh or old ones are not well-studied enough. Although some researchers deal with this assumption in their distribution planning, not enough attention has been paid to this. To fill this gap, we assume an integrated policy to consider both FIFO and LIFO policies for perishable items. The fresh products are planned with the FIFO policy and other products are scheduled by the LIFO policy to do the distribution role by stores. More specifically, the main focus of this study is on the role of stores in an inventory management system under vendor managed inventory contract (multi-period, finite time horizon) for perishable products using FIFO and LIFO stock controlling strategies. This is an extension of Crama et al. (2018) who considered an inventory model for perishable products.

Considering the above mentioned especially the latter case, needless to say that lower demand for old products makes it much more difficult to control the stock of perishable products. Therefore, buyers are not desired to purchase older products. Hence the nature of the objective function, revenues and costs change for such products which are followed by the change in the strategy of determining the optimal order quantity, Therefore, the following are considered for improving the inventory control policy:

- Products are divided into two fresh and old categories.
- A hybrid inventory policy combining FIFO and LIFO is developed to satisfy the demand of consumers.
- The proposed model reduces the price of the old products due to the remaining period of the shelf life in order to increase the consumers demand.
- The proposed model increases the cost of holding for old products due to the remaining time from the shelf life. It confirms the difficulty of the storage conditions for the old products.

Most products in the market are amongst the perishable products; the products which lose their value over time and customers have less desire to purchase them. Due to the challenges such as corruption happening in inventory management, the VMI strategy is applied and since the vendor takes the responsibility of the inventory in VMI, it is tried to control the corruption by inventory reduction. In previous models provided, the demand is supplied by FIFO or LIFO policy. In FIFO the demand is supplied first by the oldest inventory which provides less desire for the customer, while in LIFO, the demand is supplied first by the latest inventory entering the warehouse. The LIFO is applied where product reliability is important.

Hence, the proposed model is designed such that the products are divided into two groups of old and fresh products. For the old products, the demand is fulfilled by LIFO strategy and in order to approach the real world situation, the holding cost increases according to the remaining shelf life. Also, the price reduction associated with the product's remaining shelf life for these products is a suitable policy for demand stimulation and waste reduction. For perishable products, due to the slight profit margin and competition, a little price adjustment has considerable effect on sales amount and profit. In fresh products FIFO policy is used due to lower sensitivity. Finally, as mentioned above, the suggested model is useful for blood bank management, food and dairy products and pharmaceuticals which have limited shelf life.

The remainder of this paper is organized as follows. Section 2 explains framework of the proposed model and its mathematical formulation. Section 3 presents the solution method for the problem. Section 4 provides a basic numerical analysis for measuring the effect of parameters and quality of the solutions. Finally, conclusion and future remarks are summarized in Section 5.

2. Model description

The current study investigates a VMI model consisting of a set of stores. Indeed, this model is the extension of the previous works in Crama et al. (2018) wherein the minimum acceptable quality level for returned products to be remanufactured is assumed except that the current study does not contribute to the returned and remanufactured products. More specifically, this study proposes a distribution network for perishable products compared to Crama et al. (2018).

Distinguishing between old and new products, the fresh products are planed firstly by FIFO policy and then the old ones are distributed by LIFO policy in this paper where only FIFO plan is considered for all products in Crama et al. (2018). This represents the main innovation and significant contribution of this paper. Using parameter T', the products are divided into two groups of old and fresh; the products with more than T' days remaining in their shelf life are fresh and the products with less than T' days remaining in their shelf life are old. In order to satisfy demand, first the fresh products are used and applying FIFO policy we take the product with T' days of remaining shelf life and then $T'+1$ until $L-1$ (i.e. the demand is fulfilled by the oldest product). If required and in case of demand, using LIFO policy, we refer to the latest old products (i.e. the product with $T'-1$ days of remaining shelf life and then $T'-2$ until 1 day).

The objective of this problem is to determine the order quantities at the start of the periods for each store, such that the expected profit is maximized. Hence the following assumption holds generally:

In order to maximize the profits of the stores, the proposed solution computes the costs of the order and storage as well as the sales profit. This distribution network model contains the VMI policy and a plan to implement both FIFO and LIFO strategies. Moreover, the production process and the remanufacturing process are not considered in this model.

Finally, to establish the mathematics of the proposed model, the notations are:

2.1 Formulation

To satisfy the stochastic demand (we assumed that, the demand density function is estimated with using of sales' data from prior periods), three cases are assumed in the model:

1. The demand is more than total inventory and the order quantity.
2. The demand is less than the fresh products.
3. The demand is more than the fresh products and is less than the total inventory.

Considering one of the aforementioned conditions, the aim of this model is to reach the optimal order and the maximum profits for the stores. This goal is optimized with regard to FIFO and LIFO policies.

In this regard, the expected profit for $T+1$ period is:

$$f^*_{T+1,i}\left((x_1,x_2,\ldots,x_{L-1})_{T+1,i}\right)=\left(\frac{\alpha}{2}\right)I_{T+1,i} \tag{1}$$

where the right-hand side is the profit generated by the inventory left at the end of horizon and α is the rate of reduction of the purchasing price of each unit for old products which is computed by the following formula:

$$\alpha=\frac{P}{2\times(T'-1)} \tag{2}$$

Regarding the above equation, it is assumed that the old products for their last day of the shelf life will be bought as a fraction for its half of initial price. In addition, the rate of β for the growth of holding cost for the old products is calculated by the following formula:

$$\beta=\frac{0.2\times h}{(T'-1)} \tag{3}$$

From Eq. 3, it is assumed that for old products in the last day of the shelf life, a fraction of 20 percent of holding cost will be considered to compute the extra cost. Finally, the objective of proposed model ($f_{ti}(x_{ti},y_{ti})$) based on each period and the level of distribution is computing all the costs with regards to the inventory costs of the network:

$$\begin{aligned}
&f_{ti}(x_{ti},y_{ti})=-A_{ti}|\,(y_{ti}>0)-ay_{ti}\\
&-h\sum_{K=T'}^{L_1}(x_k)_{ti}-\sum_{k=1}^{T'-1}\left(h+\beta\,(T'-k)^+\right)(x_k)_{ti}\\
&+pr\,(D_{ti}>I_{ti}+y_{ti})\left[P\sum_{K=T'}^{L-1}(x_k)_{ti}+y_{ti}+\right.\\
&\left.\sum_{k=1}^{T'-1}\left(P-\alpha\,(T'-k)^+\right)(x_k)_{ti}+f^*_{t+1,i}(0,0,\ldots,0)\right]\\
&+\left(\sum_{d=0}^{I^f_{ti}}pr\,(D_{ti}=d)\left(Pd+f^*_{t+1,i}(x'_{t+1,i})\right)\right)+\\
&\sum_{d=I^f_{ti}+y_{ti+1}}^{I_{ti}+y_{ti}}pr\,(D_{ti}=d)\,P\left(I^f_{ti}+y_{ti}\right)+\\
&\sum_{k=T''+1}^{T'-1}\left(P-\alpha\,(T'-k)^+\right)(x_k)_{ti}+f^*_{t+1,i}(x''_{t+1,i})+\\
&\left(d-\left(I^f_{ti}+y_{ti}\right)-\sum_{k=T''+1}^{T'-1}(x_k)_{ti}\right)\left(P-\alpha\,(T'-T'')^+\right)
\end{aligned} \tag{4}$$

where

- $f_{ti}\ (x_{ti},y_{ti})$ is the expected profit in period t of store i.
- $A_{ti}|\,(y_{ti}>0)$ is the estimated cost-to-serve assigned in period t to store i, if $y_{ti}>0$.
- ay_{ti} is the acquisition price of order quantity in period t of store i.
- $h\sum_{K=T'}^{L_1}(x_k)_{ti}$ is the holding cost of fresh products in period t of store i (h is the holding cost of fresh product and $\sum_{K=T'}^{L_1}(x_k)_{ti}$ is the sum of fresh products).
- $\sum_{k=1}^{T'-1}\left(h+\beta\,(T'-k)^+\right)(x_k)_{ti}$ is the holding cost of old products in period t of store i ($\left(h+\beta\,(T'-k)^+\right)$ is the holding cost of old products which is multiplied by the number).

- $pr(D_{ti} > I_{ti} + y_{ti}) \left[P \sum_{K=T'}^{L-1} (x_k)_{ti} + y_{ti} + \sum_{k=1}^{T'-1} (P - \alpha (T'-k)^+) (x_k)_{ti} + f^*_{t+1,i}(0,0,...,0) \right]$ is the revenue obtained by selling the products in period t of store i if demand is more than the sum of inventory and order quantity ($pr(D_{ti} > I_{ti} + y_{ti})$ is probability of demand more than total inventory, $f^*_{t+1,i}(0,0,...,0)$ is the objective function of next period after updating inventory that is zero).
- $\sum_{d=0}^{I^f_{ti}} pr(D_{ti} = d) \left(Pd + f^*_{t+1,i}\left(x'_{t+1,i}\right)\right)$ is the revenue obtained by selling products if the demand is satisfied by the sum of new products and order quantity (Pd is the revenue obtained by selling of each new product and $f^*_{t+1,i}\left(x'_{t+1,i}\right)$ is the objective function of next period after updating inventory).
- $\sum_{d=I^f_{ti}+y_{ti+1}}^{I_{ti}+y_{ti}} pr(D_{ti} = d) P \left(I^f_{ti} + y_{ti}\right) + \sum_{k=T''+1}^{T'-1} (P - \alpha (T'-k)^+) (x_k)_{ti} + f^*_{t+1,i}(x''_{t+1,i}) + \left(d - \left(I^f_{ti} + y_{ti}\right) - \sum_{k=T''+1}^{T'-1} (x_k)_{ti}\right) (P - \alpha (T'-T'')^+)$ is the revenue obtained by selling products when old products are needed to fulfill the demand.

Following, T'' is indexed by k which is valid in Eq. 5:

$$\sum_{k=T''}^{T'-1} (x_k)_{ti} \geq d - \left(I^f_{ti} + y_{ti}\right) \tag{5}$$

The fresh products are planed firstly by FIFO policy (Crama et al., 2018). The products which are close to the shelf life are planned with LIFO policy Alvarez et al. (2020); Li et al. (2020). In this regard, following equations are provided:

$$x_{ti} = (x_{T'}, x_{T'+1}, x_{T'+2}, ..., x_{L-1}, x_L, x_{T'-1}, x_{T'-2}, ..., x_1)_{ti} \tag{6}$$

Equation 6 represents how to respond the demand by FIFO policy amongst the new products and then by LIFO policy in old products.

$$\left(x'_k\right)_{t+1,i} = \begin{cases} \left((x_{k+1})_{ti} - \left(d_{ti} - \sum_{L=T'}^{k+1} (x_L)_{ti}\right)^+\right)^+ & k = T'-1, ...L-1 \\ (x_{k+1})_{ti} & k = 1, 2, ..., T'-2 \end{cases} \tag{7}$$

Equation 7 refers to the inventory after demand deduction where demand is lower than the sum of new products and order quantity.

$$\left(x'_k\right)_{t+1,i} = \begin{cases} \left((x_{k+1})_{ti} - \left(d_{ti} - \sum_{L=T'}^{k+1} (x_L)_{ti}\right)^+\right)^+ & k = T'-1, ...L-1 \\ (x_{k+1})_{ti} & k = 1, 2, ..., T'-2 \end{cases} \tag{8}$$

Equation 8 refers to the inventory after demand deduction where demand is more than the sum of new products and order quantity.

In addition, we consider:

$$I^f_{ti} = \sum_{K=T'}^{L-1} (x_k)_{ti} \tag{9}$$

$$I^d_{ti} = \sum_{k=1}^{T'-1} (x_k)_{ti} \tag{10}$$

$$I_{ti} = I^f_{ti} + I^d_{ti} \tag{11}$$

Equation 9 represents the sum of new products, while equation 10 represents the sum of old products and equation 11 refers to total inventory So, the final model would be as:

$$\max \sum_{i=1}^{N} \sum_{t=1}^{T} f_{ti}(x_{ti}, y_{ti}) \tag{12}$$

Equation 12 is the total main objective of the problem for N stores and T periods.

$$0 \leq y_{ti} \leq c_i - I_{ti} \qquad \forall i, t \tag{13}$$

$$\sum_{K=1}^{L} (x_k)_{ti} \geq d \qquad \forall i, t \tag{14}$$

$$(x_k)_{ti}\ ,\ y_{ti} \geq 0 \qquad \forall i, t,\ \text{integer} \tag{15}$$

Constraint 13 refers to order quantity according to stock capacity. Constraint 14 refers to demand quantity. Constraint 15 shows the domain of the variables.

In order for the brief definition of the proposed problem, let's assume that there is one type of product with seven days as its maximum shelf life ($L = 7$). In this regard, the fresh products have 4 to 7 days as the shelf life ($T' = 4$) with the remaining as the old products with 1 to 3 days. The inventory states is the availability of the product with different remaining shelf life. In this example, Initial state of the system is defined as ($x_1 = 85$; $x_2 = 37$; $x_3 = 128$; $x_4 = 210$; $x_5 = 90$; $x_6 = 290$) with the probability of [0.2, 0.3, 0.2, 0.3]. it is noticeable that the demand for the product is uncertain which its probability density function is estimated based the history of the actual sales.

Fig. 1 shows the decision tree for demand of stores and accordingly, the optimal answer which addresses the customers' demand is found for these customers [x_4, x_5, x_6, x_7, x_3, x_2, x_1], respectively. Moreover, the final optimal solution at the end of the second period is [128, 10, 0, 180, 60, 380].

In order to assess the decision tree in Fig. 1, please note that nodes represent the inventory at the beginning of the period and the branches represent different demand scenarios with specific probability distributions. In this example, the beginning node is [85, 37, 128, 210, 90, 290]. These numbers indicate state of the system at the beginning of the period with shelf life of one to six days, respectively. Managers in each store decide on how much to order by checking inventory at the beginning of the period to maximize total store profits at the end of the period. Note that the orders will have the shelf life of 7 days.

In this example, products with a shelf life of 4 to 7 days are considered as new products. Conversely, the old

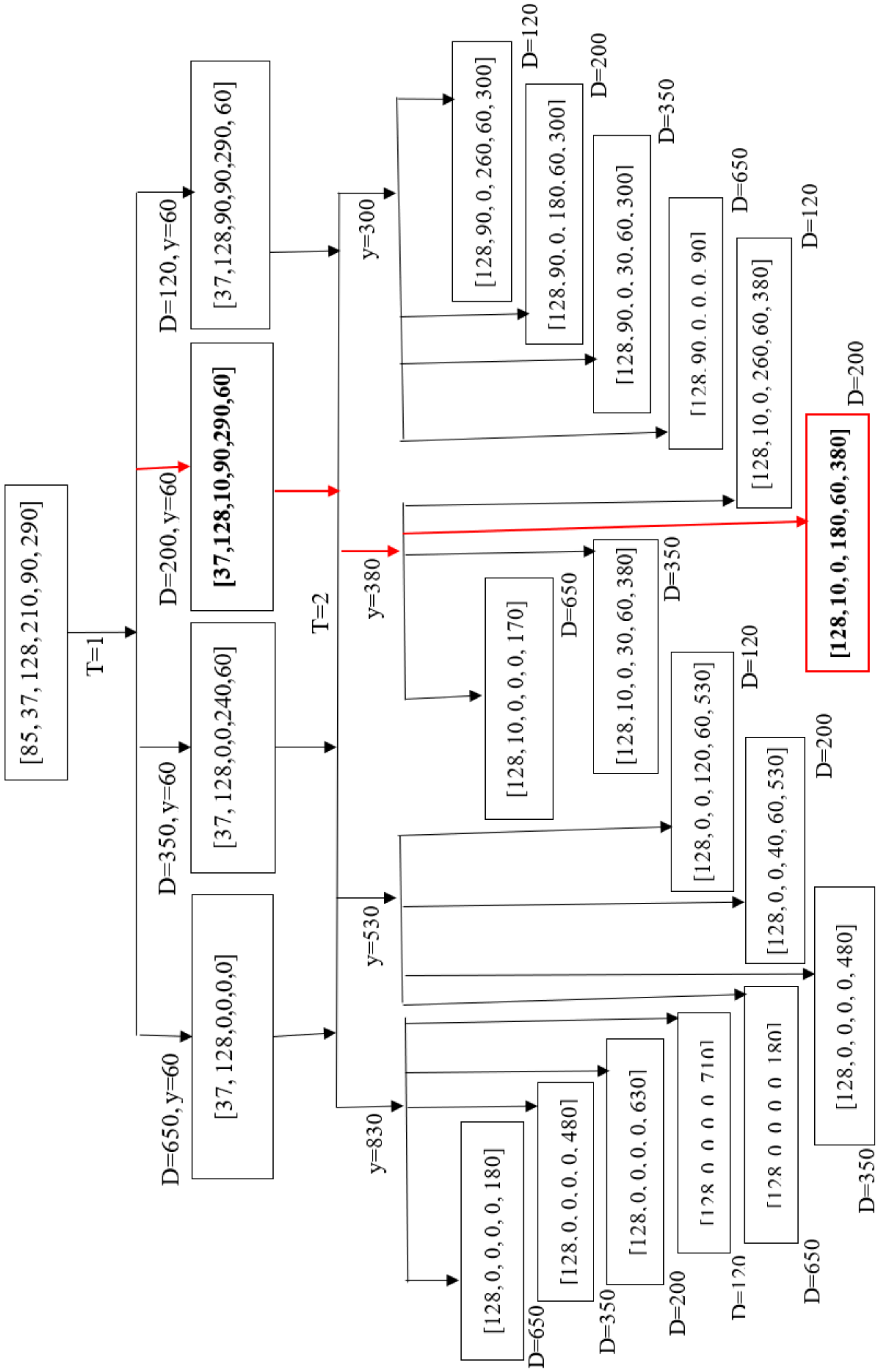

Figure 1: Decision tree for the numerical example (optimal solution is illustrated with bold-red).

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1: At the root node of the search tree, generate and insert all valid inequalities into the program. t = 1
2: List = [1]
3: while Termination check is not satisfied:
4: if there are no more nodes to evaluate then
5: Stop with the benefit and reporting decision tree
6: else
7: Select next node from list:
8: t = t (previous node) +1
9: e = previous nodes system status
10: calculate f(e)
    10.1: determine y*:
    10.2: for y = 1 to y = (ymax /ymin)
    10.3: decrease estimated cost-to-serve from f(e)
    10.4:  demand scenarios loop:
    10.5: if demand can be met by new products then
    10.6: calculate new products price and benefit that gained
    10.6: else if
    10.7: demand can be met by older products
    10.8: calculate new products price plus needed older product prices
    10.9: calculate inventory
    10.10: y* = best y found
    10.11: end if
11: Update system status based on y*
12: Update income backward based on knowledge of inventory
13: add this node to list to examine later
14: if not reached last time period then
15: Go to Select next node from list tree
16: else if
17: Choose best decision for each scenario
19: Go to the termination check.
20: end while
```

Figure 2: Pseudo–code of the solving method.

products have a shelf life of 1 to 3 days. Accordingly, the first period ($T = 1$) consists of four demand scenarios in order to respond to the customers. In either case of demand scenario and order quantity, the new products are used first and then the old ones if needed. For example, if the number of requests is 650 and the number of orders is 60, the order of response will be [x_4, x_5, x_6, x_7, x_3, x_2, x_1] with the values [210, 90, 290, 60, 128, 37, 85] respectively. In this case, the number of new products, i.e., [x_4, x_5, x_6, x_7] meets the demand and there is no need to use the old products. The same procedure is applied for other demand nodes in three other scenarios.

In order to achieve the balance at the beginning of the second period ($T = 2$), the balance of the first period is updated following the respond to the customer. Please note that the product expiring in the first period is not allowed to be used in the second period. As given in the first period, the number of demand is 650 and the order is 60. The updated inventory at the beginning of the second period is [37, 128, 0, 0, 0, 0]. With four demand scenarios existing, 16 demand scenarios exist in the second period, the procedure which is repeated in other demand scenarios.

3. Solution method

In this study the proposed model given in Eqs. 12 - 15 is solved by a Stochastic Dynamic Programming (SDP) approach. The high performance solutions of SDP have shown to determine the optimal order in studies such as Crama et al. (2018) and Nasr and Jaber (2019). This optimal solution is based on a backward strategy which considers all possible solutions numerically. In this regard, the probability of demand occurring in this period and the subsequent periods in addition to the inventory, determine the optimal order quantity. According to the backward strategy and problem solving, the inventory of each period is examined; while the optimal order quantity (y_{ti}) is determined with regard to the inventory and probability of demand.

The SDP also uses a decision tree to consider all possible cases numerically. The decision tree is a tool for decision-making when we have a number of stochastic scenarios. In order to form a decision tree with regard to the initial inventory, first we must determine the order amount for each probability of demand from the first period with initial inventory and then the allocation is applied in each store according to demand (Alvarez et al., 2020). The decision tree is $1 \times D^T$ in size (see Fig. 1 as an example).

The example illustrated in Fig. 1 is solved using the Stochastic Dynamic Programming (SDP) with a Backward Strategy. The solution procedure starts with finding the optimal policy for each step (in this example, $T = 2$). In backward strategy, the procedure moves from the end and uses the Recurrence Relation (Eq. 4), it goes from one step to the previous one and in each step, the optimum policy (the order amount for maximizing the profit) is distinguished for all forms of that step whereby the optimal order amount of the first step is finally determined.

In order to implement this algorithm, the followings are required:

- In order to customers' demand, the fresh products are allocated by FIFO policy and then LIFO policy is applied for the old products.
- The remaining inventory at the end of the period is sold at the half of the purchase price for the products.
- Finally, the proposed SDP solution is given by a pseudo-code in Fig. 2.

4. Computational results

In order to solve the model and as a numerical example, the model given in section 3 is solved by approach with the backward strategy as provided in section 4. The Eqs. 12 - 15 are solved using a code in Matlab environment. The proposed SDP using decision tree is available only for small sizes. Note that the model is coded in Intel Pentium Quad Core 3 GHz with 4 GB ram.

In this regard, the inputs of the model are as follows: the price of each product is 80$; three periods are considered with holding cost of 10$. Four demand scenarios with the probability of 0.2, 0.3, 0.2 and 0.3 are considered for the amount of the demand including 120, 200, 350

Table 1: Impact of shelf life (L) on the total profit.

Shelf life L (days)	Total profit of proposed model	Total profit in Crama et al. (2018)	Total profit with LIFO strategy
1	27200	27200	27200
2	25336	43860	38860
3	54500	65080	65020
4	80997	88780	87150
5	89008	95980	94020
6	91073	102040	101800
7	100670	102080	102020

Table 2: Results of simulated tests.

Scenario Number	Size problem	Proposed model		Model in Crama et al. (2018)	
	(i, T, T', L, P)	Total profit	Order quantity (y^*)	Total profit	Order quantity (y^*)
1	(1, 2, 2, 3, 60)	42000	0	48680	0
2	(1, 2, 2, 3, 80)	56350	0	65080	0
3	(1, 3, 4, 5, 90)	92400	170	94250	180
4	(1, 4, 4, 6, 90)	92400	170	95200	180
5	(1, 5, 4, 6, 90)	92400	170	98400	190
6	(2, 3, 2, 2, 60)	124800	350	132800	650
7	(2, 3, 2, 2, 80)	185600	350	185600	650
8	(2, 3, 3, 5, 90)	191200	880	194800	990
9	(2, 3, 4, 6, 120)	264000	880	294560	980
10	(2, 4, 2, 2, 60)	113500	550	134200	650
11	(2, 4, 2, 2, 90)	183500	580	212000	670
12	(2, 4, 3, 6, 90)	153300	780	184800	940
13	(2, 5, 3, 6, 90)	263600	880	278600	930
14	(2, 5, 5, 7, 120)	314000	900	328000	940
15	(2, 5, 4, 6, 90)	262400	900	277000	950

and 650 respectively. The initial inventory is zero and the capacity of each store is 1000 products. The State of the system of the vendor managed inventory contract is $[x_1 = 85, x_2 = 37, x_3 = 128, x_4 = 210, x_5 = 90, x_6 = 290]$.

As given in Table 1, we analyze the impact of shelf life (L) on the total profit of proposes model in comparison with basic model. It should be noted in our proposed model, if $T' = 1$, proposed model is transformed into the basic model given in Crama et al. (2018) and if $T' = L$ and $\alpha = \beta = 0$, proposed only follows the LIFO strategy.

Based on the results of Table 1, the behavior of these objectives is drawn in Fig. 3. As it is obvious, the profit of proposed model with simultaneous use of FIFO and LIFO policy is lower than the basic model (only using FIFO policy) and LIFO strategy model. As such, the profit of LIFO strategy is slightly lower than the profit of model in Crama et al. (2018) in a very competitive way. Although our model has a low profit in this comparison, it increases the customers' satisfaction as always fresh foods will be allocated to the stores and reduces waste food. In addition to the impact of shelf life (L) on the profits, as given in Table 1, we compare the results of proposed model with its basic version as reported in Crama et al. (2018). In this regard, 15 random test problems have been generated

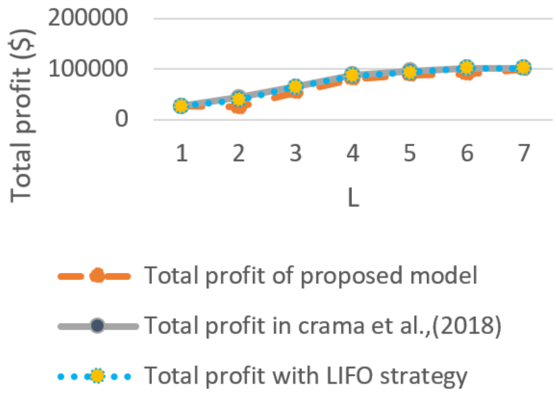
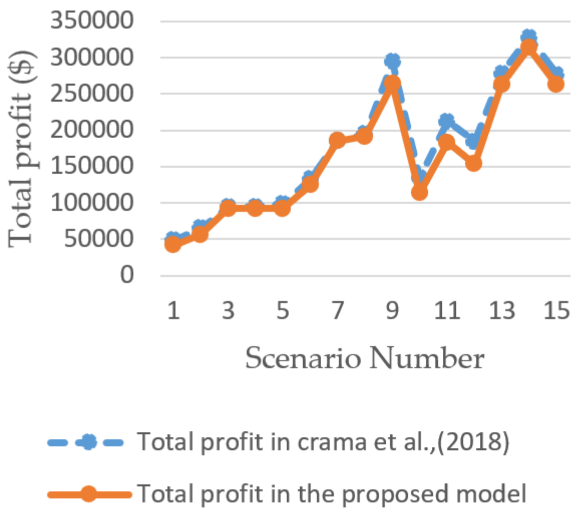


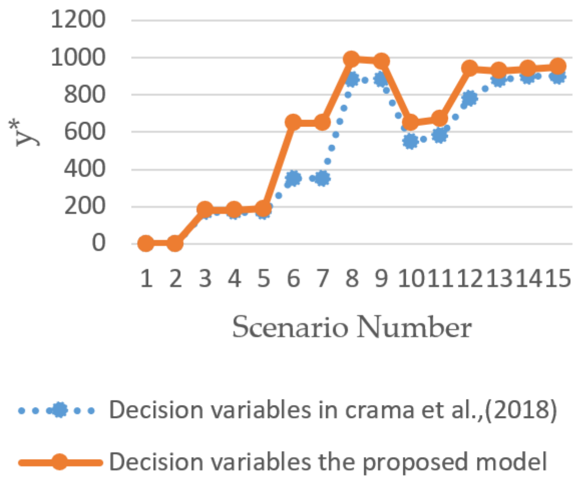
Figure 3: Impact of shelf life (L) on the total profit.

with different sizes and complexities. The problem size as the scenario number per test is given in Table 2. The initial inventory and demand are the same in all the tests. Besides, the total profit of both models and the summation of the main decision variable (y_{ti}) are reported in this table. The behavior of the objectives (Fig. 4a) and the amount of decision variables (Fig. 4b) are depicted in Fig. 4.

The sensitivity analysis is performed on three important parameters including α, β and T'. In our SDP, the



(a)



(b)

Figure 4: Comparison of proposed model with the study of Crama et al. (2018); (a) based on the total profit; (b) based on the amount of main decision variables.

rate of α in Eq. 2 is 13.3, β in Eq. 3 is 0.66 and T' is 4. In order to show the impact of these parameters, four inputs are given and then, the behavior of the objective function given in Eq. 12 is analyzed.

The results are given in Table 3, 4 and 5 in addition to the behavior of the objective is shown in Figs. 5 and 6.

First of all, the Figs. 5 show parameter α directly affects the objective function. This parameter can reduce the profits in the objective function.

Secondly, reveals that a well-tuned value of this factor is of high importance as it reduces the total profits. This factor should be considered by a low value for the managers if they want to improve the performance of their inventory system.

Furthermore, we compare the objective functions with regard to different scenario numbers for the range of α and β as depicted in Fig. 5. This sensitivity analysis shows that α has a higher impact on total profit of the proposed model when compared to β.

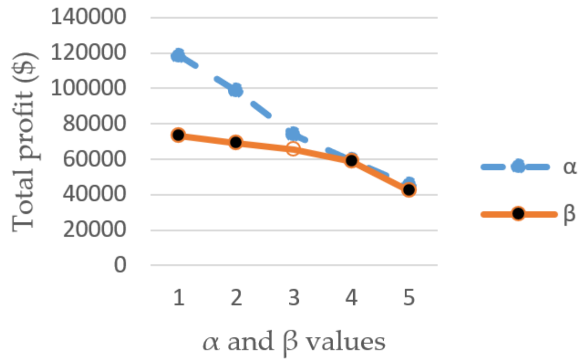


Figure 5: The sensitivity analysis on α and β based on the objective function.

Table 3: The sensitivity analysis on α.

Scenario Number	α	Objective function ($)
C1	0	118400
C2	5	98600
C3	10	73800
C4	15	59300
C5	20	45400

Table 4: The sensitivity analysis on β.

Scenario Number	β	Objective function ($)
C1	0	73400
C2	5	69200
C3	10	65400
C4	15	58800
C5	20	42350

Table 5: The sensitivity analysis on β.

Scenario Number	T'	Objective function ($)
C1	1	116800
C2	2	113900
C3	3	101500
C4	4	99800

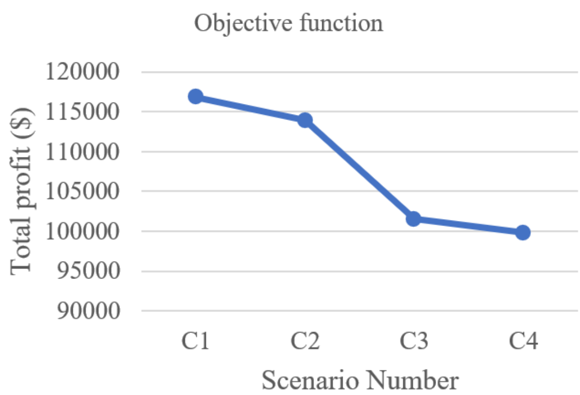


Figure 6: The sensitivity analysis on T' based on the objective function.

Lastly, the behavior of the objective function as depicted in Figs. 6 it is confirmed that the use of FIFO policy for fresh products increases the profits of the model. Given more time to FIFO policy and then applying LIFO policy, it will be useful to sell the products which are close to its shelf life. For example, from one through two days of change in inventory policy, the profits of the model show a high growth compared to the other cases. It should be noted that if T' is one, the model cannot distinguish between FIFO and LIFO strategies and the model would be the same as the basic one as proposed by Crama et al. (2018).

What we can see is that the profits of the stores are generally more sensitive to the changes of inputs in case of stores complexity and shelf life of products in contrast to the case of product's price concerning FIFO and LIFO policies.

5. Conclusion

In this paper, concerning to recent changes in the retailing systems favored by the vendor managed inventory models; a novel VMI policy for a set of stores was developed. To identify the contributions of the proposed model and to distinguish it from the previous works, several extensions have been added. In the real problem, the proportion of perishable products with regards to the fresh or old ones are not well-studied enough. Although some researchers deal with this assumption in their distribution planning, not enough attention has been paid to this. To fill this gap, we assume an integrated policy to consider both FIFO and LIFO policies for perishable items. The fresh products are planned with the FIFO policy and other products are scheduled by the LIFO policy to do the distribution role by stores. Therefore, the significant contribution of this paper is to propose a VMI including a set of stores to focus on the inventory management for perishable products with both FIFO and LIFO strategies. The effects of these factors were analyzed via a set of sensitivities. The model was solved by the SDP based on the backward strategy. One finding is that a tuned level for the main important parameters of the model, i.e., α and β, decrease the total profit of the proposed model.

The products in the proposed model are divided into two groups of old and fresh and the integrative policy of FIFO and LIFO is applied. In case of fresh products with FIFO policy, it is in accordance with vendors' taste and in case of old products which customers don't have desire to buy, LIFO policy is applied to relatively satisfy the customers' needs and using the incentives like discount, the old products are almost sold before their expiration date. Considering the probability of demand, discount policy could probably increase the demand which causes more old products to be sold which reduces the waste and holding costs. Finally, the results also confirm the applicability and high efficiency of the proposed model in real concepts of the VMI.

For future studies, there are many insightful recommendations. The proposed problem can be extended by adding sustainability factors such as the green emissions, suppliers' risk and satisfaction levels. More broadly, employing metaheuristics is another good continuation of this study.

Nomenclature

Indices

i: Index of stores.
t: Index of periods.
k: Index of remaining shelf life of product.

Parameters

N: Number of stores.
P: Selling price of each unit of the product.
α: Rate of reduction of the purchasing price of each unit for old products.
L: The maximum shelf life of the product.
h: Holding cost per unit.
D_{ti}: Demand of store i in period t (This parameter is generated randomly).
T: Length of the planning horizon.
c_i: Capacity of store i.
A_{ti}: Estimated cost-to-serve assignment of store i in period t.
β: Rate of growth of holding cost for old products.
T': A part of shelf life to define the fresh products and the old products.
$P(D_{ti} = d)$ Probability function of the demand of store i in period t.
$x_{ti} = (x_1, x_2, \ldots x_{L-1})_{ti}$: State of the system in each period for each store before delivery (the inventory level before replenishment). For example, x_1 means the number products which has one day as their shelf life.
$(x_k)_{ti}$: The number of products which have k days as the shelf life.
a: Acquisition price of each unit of the product.

Decision Variable

y_{ti}: Order quantity in period t for the store.

References

Akbari Kaasgari, M., Imani, D. M., and Mahmoodjanloo, M. (2017). Optimizing a vendor managed inventory (VMI) supply chain for perishable products by considering discount: Two calibrated meta-heuristic algorithms. *Comput. Ind. Eng.*, 103:227–241.

Alvarez, A., Cordeau, J.-F., Jans, R., Munari, P., and Morabito, R. (2020). Formulations, branch-and-cut and a hybrid heuristic algorithm for an inventory routing problem with perishable products. *Eur. J. Oper. Res.*, 283(2):511–529.

As'ad, R., Hariga, M., and Alkhatib, O. (2019). Two stage closed loop supply chain models under consignment stock agreement and different procurement strategies. *Appl. Math. Model.*, 65:164–186.

Aschemann-Witzel, J. (2018). Consumer perception and preference for suboptimal food under the emerging practice of expiration date based pricing in supermarkets. *Food Qual. Prefer.*, 63:119–128.

Buzby, J. C. and Hyman, J. (2012). Total and per capita value of food loss in the United States. *Food Policy*, 37(5):561–570.

Chołodowicz, E. and Orłowski, P. (2021). Development of new hybrid discrete-time perishable inventory model based on Weibull distribution with time-varying demand using system dynamics approach. *Comput. Ind. Eng.*, 154:107151.

Cohen, M. A. and Prastacos, G. P. (1981). Critical number ordering policy for LIFO perishable inventory systems. *Comput. Oper. Res.*, 8(3):185–195.

Crama, Y., Rezaei, M., Savelsbergh, M., and Woensel, T. V. (2018). Stochastic inventory routing for perishable products. *Transp. Sci.*, 52(3):526–546.

Disney, S., Potter, A., and Gardner, B. (2003). The impact of vendor managed inventory on transport operations. *Transp. Res. Part E Logist. Transp. Rev.*, 39(5):363–380.

Gani, A. and Sabarinathan, G. (2013). Optimizing advertising, pricing and inventory policies in VMI production supply chains with compensating cost in fuzzy environment. *J. Appl. Math. Fluid Mech.*, 5:1–21.

Garrone, P., Melacini, M., and Perego, A. (2014). Opening the black box of food waste reduction. *Food Policy*, 46:129–139.

Hemmati, A. and Afshar-Nadjafi, B. (2017). The influence of processing on the optimal inventory policy for deteriorating products. *Lat. Am. Appl. Res.*, 47(4):137–143.

Janssen, L., Claus, T., and Sauer, J. (2016). Literature review of deteriorating inventory models by key topics from 2012 to 2015. *Int. J. Prod. Econ.*, 182:86–112.

Júnior, A. G., Santade, H. O., Pizzinatto, N. K., and Farah, O. E. (2005). CRM: Conceitos e métodos de aplicação no marketing de relacionamento. *Rev. Gestão Ind.*, 1(3).

Li, Y., Chu, F., Côté, J.-F., Coelho, L. C., and Chu, C. (2020). The multi-plant perishable food production routing with packaging consideration. *Int. J. Prod. Econ.*, 221:107472.

Momeni, S. and Afshar-Nadjafi, B. (2020). Replenishment policy for a processing system with stochastic constraints. *Lat. Am. Appl. Res.*, 51(1):37–42.

Mousavi, R., Bashiri, M., and Nikzad, E. (2022). Stochastic production routing problem for perishable products: Modeling and a solution algorithm. *Comput. Oper. Res.*, 142:105725.

Nasr, W. W. and Jaber, M. Y. (2019). Supplier development in a two-level lot sizing problem with non-conforming items and learning. *Int. J. Prod. Econ.*, 216:349–363.

Polotski, V., Kenne, J.-P., and Gharbi, A. (2017). Production and setup policy optimization for hybrid manufacturing–remanufacturing systems. *Int. J. Prod. Econ.*, 183:322–333.

Safaeian, M., Fathollahi-Fard, A. M., Tian, G., Li, Z., and Ke, H. (2019). A multi-objective supplier selection and order allocation through incremental discount in a fuzzy environment. *J. Intell. Fuzzy Syst.*, 37(1):1435–1455.

Stefan, V., van Herpen, E., Tudoran, A. A., and Lähteenmäki, L. (2013). Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. *Food Qual. Prefer.*, 28(1):375–381.

Transchel, S. and Hansen, O. (2019). Supply planning and inventory control of perishable products under lead-time uncertainty and service level constraints. *Procedia Manuf.*, 39:1666–1672.

Wilson, N. L., Rickard, B. J., Saputo, R., and Ho, S.-T. (2017). Food waste: The role of date labels, package size, and product category. *Food Qual. Prefer.*, 55:35–44.