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Integrated Pricing and Inventory Control for Perishable Products, Taking into Account the Lack of Backlog and Inventory Management Policy by the Seller

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Abstract. Recently, utilizing appropriate inventory control policy and determining the optimal selling price for various goods has been the main topic of scientific and industrial research. Inventory management policy 1 by the seller is one solution that improves the chain's performance by creating coordination between members of the supply chain. The current study attempts to devise an integrated model of inventory pricing and control under the inventory management policy by the seller for perishable goods with shortages is considered. The purpose of presenting the model is to determine the optimal price, the optimal repayment time, and the order size, in order to maximize the profit. To acquire those optimal values, the profit functions of the buyer and the seller are taken into account. Given

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the results acquired, it is demonstrated that at any cost, the repayment time is unique and optimal. It is concluded that with the optimal recovery time available, the objective function is a concave function of price, and its optimal value is available. Furthermore, utilizing the inventory management policy by the seller could be a proper means to reducing retailer costs while raising their profit.

Keywords: Inventory control policy, perishable products, shortage, pricing, optimal order quantity.

1. Introduction

Goods pricing is one of the critical issues in today's world. This is mainly due to the fact that the economic crisis has been significant not only in developing countries but also in developed countries [1-3]. Given the increased price of raw materials and energy, any system is forced to adopt optimal pricing policies because providing better products compared to competitors and using accurate strategies to reach a good status among competitors are some of the essential principles for achieving profitability in the business model [4-7]. In other words, pricing is the most crucial part of a business model, and related decisions have extreme impacts on an agency's productivity [8,9]. On the other hand, a company will suffer a loss in case of inaccurate performance, such as offering high-priced or low-priced goods [10-12]. Pricing requires an initial estimation of all costs and adopting an appropriate policy that fits this amount of costs [13]. Today, dedicating efforts to earning high revenues and attracting and retaining customers has become one of the most important issues due to the competitive environment of global markets [14,15]. Therefore, cooperation between the members of a system for survival in the competitive circle among other suppliers and reduction of costs has become a necessity in the strategies of companies [16,17].

Meanwhile, vendor-managed inventory (VMI) has attracted much attention in today's world. According to this policy, the seller has full knowledge of buyer sales (retail), inventory level, and type of goods in stock [18]. Therefore, the manufacturer can determine the appropriate time for ordering raw materials to produce products [1,14]. This policy has led to a general attitude in supply chain distribution channels, which allows manufacturers, suppliers, and retailers to improve production, reduce inventory and increase inventory turnover and accessibility. By having access to this comprehensive information, manufacturers can better adapt their production program to the needs of customers [19-21].

2. Literature Review

Given the importance of the supply chain in inventory management in retail stores, VMI can be implemented in both distribution centers and stores [14]. The most apparent advantage of VMI is reducing costs for suppliers and retailers, ultimately increasing profit. Price is so important in the level of buyer profit (retailer) that a large part of the literature has been dedicated to issues such as pricing and continuously determining inventory for perishable products in the past few years. Eilon and Mallaya [6] were the first scholars who considered the inventory model with price-dependent demand. Chen and Chen [3] evaluated dynamic pricing and optimal size problem for instant perishable goods considering that perishability rate is a linear function of time and demand is a function of time and price of selling goods.

Tsao and Sheen [16] presented a dynamic pricing problem for perishable goods by considering the delay in payments and advertisement assumptions. These scholars defined demand as a non-linear function of time and a linear function of price. In this research, advertisement cost was added to the total costs. According to these researchers, since the objective function is a concave function of price, there is an absolute optimal price.

Over the past few years, inventory control policies have attracted more attention among sellers. The conceptual structure of VMI was expressed by Haddouch et al. [7] as follows: "who is responsible for inventory control?". Pasandideh et al. [13] evaluated the effect of VMI in a two-layer supply chain. They used mathematical calculations to compare the total chain costs in two traditional and modern modes. Notably, buyer (retailer) shortage was permitted and expressed as delayed order. Dai et al. [4] presented a heuristic for inventory control and periodic routing. They considered products perishable and a VMI system for inventory management in the supply chain. To get closer to the real world, product demand was formulated as a function of price and inventory. Chen et al. [2] evaluated the topic of risk aversion in a VMI system for a supply chain. To this end, they defined a type of joint contract among the supply chain members and assessed the efficiency of this type of contract. Omar et al. [12] used a blockchain system to improve VMI in a supply chain. Accordingly, blockchain technology will help minimize value at risk in the entire chain. This technology is applied by defining smart contracts to be exchanged among the supply chain members in a short period.

Considering the literature, it can be inferred that there is a gap in the arena of integrated pricing and inventory control under the VMI policy. To be specific, no previous research has comprehensively evaluated a combination of pricing and inventory control for instant perishable products and entering managerial techniques, including inventory control policy by the seller, which is fully discussed in the current study. Hence, the current study intends to present an integrated model of pricing and inventory control for perishable goods by considering shortages and inventory control policy by the seller. The study results can contribute to reducing retailer costs while increasing their profit, as well as leading to a decreased number of orders.

3. Statement of the Problem

To present the model, we use the following symbols:

A_V	Fixed cost of ordering for the buyer in each period
A_B	Fixed cost of ordering for the seller in each period
C	Cost of purchasing each unit of goods
p	Cost of selling each unit of goods
h	Maintenance cost per unit of inventory per unit of time
T	Replenishment duration
α, β	Fixed demand parameters
π	Cost of shortage per product unit per unit time
θ	Perishability rate
I_{max}	Maximum inventory in each period
$I(t)$	Level of inventory at t time
Q	Level of ordering in each period
TP_B	Buyer profit

TP_V Seller profit
F Percentage of cycle length in which the system does not experience a shortage
$D(p)$ Demand function in each period
b Level of shortage in each period

3.1. Assumptions

Assumptions are considered in nearly all models in the inventory control field. However, part of these assumptions is real, and another part is theoretical, which is mostly presented for performing calculations and preventing the high complexity of the models. In the present study, we consider the following assumptions:

- The model is presented for one type of perishable product.
- The delivery period is zero, and the replenishment rate is considered to be infinite.
- Demand function is considered as $D(p) = \alpha - \beta p$, which is continuous, linear and descending relative to price.
- Goods that perished over time are not replaced or repaired.
- Shortage occurs in the system and is in the form of a complete backlog.
- The perishability rate (θ) is considered to be fixed, and $0 < \theta < 1$.
- The desired supply chain includes two layers of buyer and seller, where the buyer makes an order to the seller based on the final customer demand level.

4. Materials and Methods

4.1. Modeling

In this section, similar studies performed by Pentico and Drake [14] are considered. Meeting demands and reducing perishability decrease in each inventory round for two reasons. A shortage takes place in the system when inventory reaches zero, which is deemed a complete backlog. Figure 1 demonstrates the inventory system in that mode. As seen in the figure, the system period is split into two periods of [0, FT) and (FT, T). Regarding that, FT is when the inventory system doesn't undergo a shortage, whereas the (1-FT)T period is when the system faces a shortage. In the [0, FT) period, the inventory level goes down because of meeting demand and the goods' perishing. As a result, regarding the features of differential equations, the inventory level is demonstrated in the period by Equation 1:

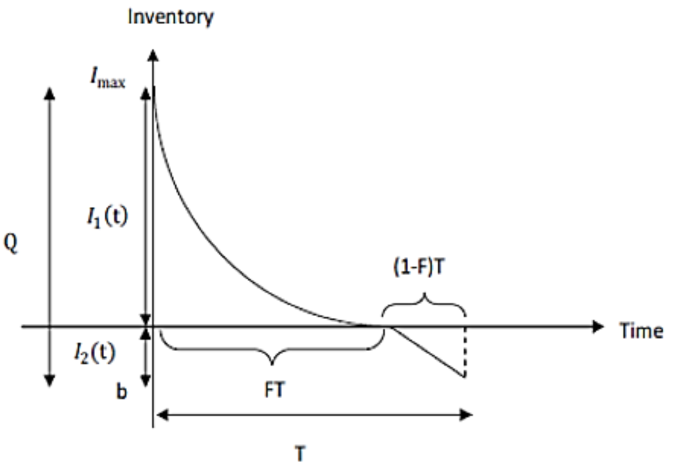

Figure 1. Order economic model for perishable goods considering shortage as backlog

$$\frac{dI_1(t)}{dt} = -D(p) - \theta I_1(t), \qquad 0 < t < FT \tag{1}$$

Considering that $I_1(FT) = 0$, the inventory level can be estimated based on the following equation:

$$I_1(t) = \frac{D(p)}{\theta}(e^{\theta(FT-t)} - 1), \qquad 0 < t < FT \tag{2}$$

According to the figure, it is clear that the inventory level reaches zero in FT time, and a shortage occurs in the system. In the period of [FT, T), the inventory level only depends on demand and the inventory level equation is obtained from Equation 3.

$$I_2(t) = -D(p)(t - FT) \qquad F(T) < t < T \tag{3}$$

Afterwards, the maximum shortage level is calculated using Equation 4.

$$b = -I_2(t) = -D(p)(1 - F)T \tag{4}$$

As illustrated in Figure 1, if t is given a zero value in Phrase 2, we will lose the maximum inventory level at hand in each period. That demonstrates the maximum amount at hand at the start of the period since no product has been sold yet. Thus, there will be:

$$I_1(t = 0) = \frac{-D(p)}{\theta}\left(e^{\theta FT} - 1\right) \tag{5}$$

To simplify the calculations, we apply the Taylor series, which is shown in three sentences in Equation 6.

$$e^{\theta FT} = 1 + FT\theta + \frac{(FT\theta)^2}{2!} \qquad FT\theta \ll 1 \tag{6}$$

After the implementation, we will have:

$$I_{max} = D(p) = TF(1 + \frac{TF\theta}{2}) \tag{7}$$

In order to attain the ordering amount in each period, we need to add together the amount of shortage in each period and the maximum amount of inventory available at the beginning of the period. The buyer makes enough orders to remove the shortage of the previous period and satisfy the demands of the customers in each period, which is based on the final customer demand. Hence, there will be:

$$Q = I_{max} + b = D(p) = TF\left(1 + \frac{TF\theta}{2}\right) + (1 - F) * T * D(p) \tag{8}$$

As mentioned before, the main subject of the present research is to find the optimal sales price and duration of replenishment and a percentage of the cycle length where there is no shortage, such that the buyer profit is maximized. To acquire those values, the profit functions of the buyer and the seller should be determined first. The objective functions are calculated according to what was previously stated. As mentioned before, the desired supply chain has two layers: a buyer (retailer) and a seller (supplier). The first layer (buyer (retailer)) determines how much order to make on the basis of the level of final customers' demand. That is essential because the buyer will incur costs depending on the amount of inventory available. The costs considered for the seller in the current research include ordering costs, goods purchasing costs, maintenance costs, shortage costs, and perishability costs. In the inventory control policy model, the seller must pay all costs. Therefore, the buyer and seller profit functions are obtained from equations 9 and 10. The first phase of Equation 9 is the revenue from the sale of goods to the end customer, while the second phase is the cost of purchasing goods from the supplier. Phrases of Equation 10 are revenue from the sale to the buyer (retailer), the buyer and seller ordering costs, the perishability costs, goods storage costs, and shortage costs, respectively.

$$TP_B = p(\alpha - \beta p) - C\left[D(p)F\left(1 + \frac{TF\theta}{2}\right) + (1 - F)D(p)\right] \tag{9}$$

$$TP_V = C\left[D(p)F\left(1 + \frac{TF\theta}{2}\right) + (1 - F)D(p)\beta\right] - \frac{A_B + A_V}{T} - \frac{CD(p)TF^2\theta}{2} - hD(p)\frac{T(F)^2}{2} \tag{10}$$

4.2. Solution Method

In this section, the desired method is that the buyer determines their optimal price and presents it to the seller. Since the seller must pay all buyer costs due to the VMI policy, the seller determines the optimal period of replenishment and the non-shortage period in the system based on the optimal price adopted by the buyer. Therefore, to find the optimal price proposed by the buyer to the seller, the derivative of the buyer's profit function to price is calculated, which is equal to zero.

$$\frac{\partial TP_B}{\partial p} = \alpha - \beta p - c\left(-\beta(1-F) - \beta F\left(1 + \frac{TF\theta}{2}\right)\right) = 0 \tag{11}$$

If the solution obtained from Phrase 11 is to be optimal, the second root of the derivative of the buyer profit function to p must be negative, assuming that T and F have fixed values. Therefore, we will have:

$$\frac{\partial^2 TP_B}{\partial p^2} = -2\beta < 0 \tag{12}$$

Concerning the mentioned calculations, the buyer determines their sales price on the basis of Phrase 11 and provides it to the seller. Next, the seller makes a decision according to the offered price relative to finding the optimal T and F values such that profit is maximized. To this end, a derivative of the seller profit function relative to F and T must be calculated, and the obtained result must be equated to zero. Asa result, the price acquired from Phrase 11 in the seller profit function is replaced as the optimal price.

$$TP_v = \frac{1}{4}T\big(-2\alpha - \beta c(2 + F^2T\theta)\big)\left[c\left(\left(\frac{\theta TF}{2}\right) + 1\right) - \pi\frac{T(1-F)^2}{2} - c\frac{T\theta F^2}{2} - h\frac{TF^2}{2}\right] - \frac{A_B + A_V}{T} \tag{13}$$

To attain the optimal values of T and F in such a way that the seller profit function is maximized, we have to determine the derivative of Phrase 13 relative to T and F.

$$\frac{\partial TP_V}{\partial F} = \frac{1}{4}T(-2\alpha(-\pi + F(h+\pi)) + \beta c(-2\pi + F^2\pi T\theta) + F(2h + 2 + 2c\theta - \pi T\theta))) \tag{14}$$

$$\frac{\partial TP_V}{\partial T} = \frac{A_B + A_V}{T^2} - \frac{1}{4}\beta cF^2\theta\left(-\frac{1}{2}F^2hT - \frac{1}{2}(1-F)^2\pi T - \frac{1}{2}cF^2T\theta + c\left(1 + \frac{1}{2}F^2T\theta\right)\right) + \frac{1}{4}\left(-\frac{F^2h}{2} - \frac{1}{2}(1-F)^2\pi\right)\left(2\alpha - \beta c(2 + F^2T\theta)\right) \tag{15}$$

To find the optimal T and F solution, equations 14 and 15 must be solved in the form of a system of two unknown equations. It needs to be proven that the solutions acquired from solving the mentioned system are maximum points. To do so, the second derivative of the seller profit function relative to T and F has to be proven to be negative, and determinants of the Hessian matrix of this function is positive.

$$\frac{\partial^2 TP_V}{\partial T^2} = \frac{-8(A_B + A_V) + \beta cF^2(\pi - 2F\pi - f^2(h+\pi))T^3\theta}{4T^3} < 0 \tag{16}$$

Based on the mentioned equation, the condition of negative second derivative of the function relative to T is established.

$$\frac{\partial^2 TP_V}{\partial F^2} = \frac{1}{4}T(-2a(h+\pi) + \beta c(2h + 2c\theta + \pi(2 + (-1 + 2F)T\theta))) \tag{17}$$

Conditions 18 and 19 must be established for the mentioned phrase to be negative:

$$2\beta c < a \tag{18}$$

$$h \geq (c\theta + (2F - 1)T\theta) - \pi \tag{19}$$

Regarding the positive demand and conditions inserted in Taylor series, conditions 18 and 19 are always established. As a result, the initial condition of optimality of the achieved points is affirmed. In order to assess the establishment of the second condition, we need to calculate the determinants of the Hessian matrix

$$\det(H) = \left[\left(\frac{\partial^2 TP_V}{\partial F^2}\right) * \left(\frac{\partial^2 TP_V}{\partial T^2}\right) - \left(\frac{\partial^2 TP_V}{\partial F \partial T}\right)^2\right] \tag{20}$$

Since the phrases are long, it is not possible to simplify them manually. Therefore, they are simplified with Mathematica Software. With regard to conditions 21-24, the Phrase 20 is positive. Therefore, if equations 21-24 are established, the achieved solution is optimized.

$$a > \frac{\beta c(5 + 2T\theta F^2 - 6F)}{2} \tag{21}$$

$$A_B + A_V > \frac{cT^2 F\pi(\pi + h + c\theta)}{8h} \tag{22}$$

$$\frac{2\pi + c\theta}{4(\pi + h + c\theta)} < F < \sqrt{\frac{\pi}{h + \pi + c\theta}} \tag{23}$$

$$T\theta F^2 < \frac{a}{3\beta c} \tag{24}$$

Considering the positive demand and conditions inserted in Taylor series, conditions 18-24 are almost always established.

5. Results and Discussion

The following numerical example is presented to make the mentioned solution method clear. Tables 1 and 2 show the data related to the problem and the optimal solution. Afterward, results related to sensitivity analysis are presented in Table 3.

Table 1. Numerical example's parameters

Parameters	π	θ	a	b	c	h	A_B	A_v
Values	80	0.08	500	0.5	200	40	250	250

Table 2. Numerical example's results

Variables	T^*	F^*	Q^*	P^*	TP_V^*	TP_B^*	T_{Total}^*
Numerical example results	0.27	0.623	53	600.425	37400.1	79826.3	117227

Table 3. Sensitivity analysis results

Parameters	Changes (%)	T^*	F^*	P^*	TP_B^*	TP_V^*	Q^*
$A_B + A_V$	+50	0.34	0.62	600.53	79787	36815	68
	+25	0.31	0.62	600.48	79805	37093	62
	-25	0.23	0.62	600.37	79849	37748	47
	-50	0.19	0.62	600.30	79877	38161	38

C	+50	0.28	0.59	650.59	61040	49960	45
	+25	0.28	0.61	625.67	70059	44296	48
	-25	0.27	0.64	575.33	90169	29342	57
	-50	0.27	0.65	550.23	101146	22242	59
H	+50	0.23	0.55	600.66	79885	37049	46
	+25	0.25	0.58	600.5	79860	37206	50
	-25	0.36	0.67	600.3	79773	37644	72
	-50	0.37	0.68	600.2	79735	37917	76
π	+50	0.26	0.71	600.54	79783	37267	64
	+25	0.26	0.67	600.48	79808	37255	58
	-25	0.29	0.56	600.3	79849	37135	52
	-50	0.32	0.48	600.2	79878	37089	49
θ	+50	0.29	0.61	600.6	79738	37427	55
	+25	0.28	0.62	600.5	79782	37414	53
	-25	0.26	0.63	600.3	79869	37384	49
	-50	0.25	0.64	600.2	79912	37368	47

The table above demonstrates the results associated with the sensitivity analysis. Considering the results, a rise in price leads to an increase in the replenishment period, which is generally regarded as normal. The buyer desires to keep the inventory for longer thanks to the high ordering cost so as to order less often. The rise in purchasing costs leads to an increase in sales costs, which appears natural, and the price sensitivity to this parameter is quite high. An increase in storage costs results in a decrease in the replenishment period, number of orders, and a percentage of the cycle length where the system doesn't face a shortage while the sales price goes up. As the shortages' cost rises, so does the amount of ordering and selling prices and the non-shortage length of time.

6. Conclusion

Over the course of this study, pricing and inventory control constantly are considered for perishable goods under the policy of inventory control by the seller. Mathematical analyses have been performed, and their optimal results were determined and calculated by certain approaches. Attempts were made to present the proof of the theorems utilized as much as possible. A numerical example was presented to clear the subject further, and sensitivity analysis was conducted in several model parameters. It was shown that the existence of techniques on the supplier side for the retailer could raise retailer's profit. Utilizing the inventory management policy by the seller is an effective way to reduce retailer costs while increasing their profit. In addition, it results in a decreased number of orders.

In regard to future studies, it is suggested that probable (random) and fuzzy demands be utilized. As mentioned, definitive demand was employed in the course of this study. Since there has recently been an increase in the tendency to probable and fuzzy demands (to get closer to real-world conditions), it is recommended that the models proposed in this study be designed and investigated by fuzzy and possible demands.

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