IMPACT OF CUSTOMER RETURNS AND TRADE CREDIT FOR DETERIORATING ITEMS WITH PRESERVATION TECHNOLOGY INVESTMENT UNDER PRICE-SENSITIVE DEMAND

Mrudul Y. Jani*, Vaidehee M. Soni** and Manish R. Betheja*
Department of Applied Sciences, Faculty of Engineering and Technology
Parul University, Vadodara-391760, Gujarat, India
**Parul Institute of Applied Sciences, Faculty of Applied Sciences,
Parul University, Vadodara-391760, Gujarat, India

ABSTRACT
To increase the demand for the product, permissible delay in payment is an essential tool in the corporate world. This paper focuses on the optimal ordering policies where the supplier gives mutually agreed trade credit to the retailer. In the article, the synchronized determination of selling price and inventory replenishment when the customer returns the product to the company are given due importance. The demand is the price-sensitive quadratic type which is more suitable for seasonal products. As most of the products lose their utility over time, this paper also considers the constant deterioration rate of the product. Moreover, to reduce the effect of deterioration, many retailers spend money to preserve the product. This model also deals with the preservation of technology investment. The main aim of this research article is to obtain optimal selling price, cycle time, and preservation technology investment that maximizes the total profit of the retailer. This model is supported by numerical examples and also recognized the best scenario of the model by graphical outcomes, in three dimensions. Sensitivity analysis of major parameters is done to deduce decision-making insights.

KEYWORDS: Inventory; permissible delay period; price-sensitive time-dependent demand; customer return; the constant rate of deterioration; preservation technology.

MSC: 90B05

RESUMEN
Para aumentar la demanda del producto, la demora permisible en el pago es una herramienta esencial en el mundo corporativo. Este documento se centra en las políticas de pedidos óptimas en las que el proveedor otorga crédito comercial acordado mutuamente al minorista. En el artículo, se da la debida importancia a la determinación sincronizada del precio de venta y la reposición de inventario cuando el cliente devuelve el producto a la empresa. La demanda es del tipo cuadrático sensible al precio que es más adecuado para productos de temporada. Como la mayoría de los productos pierden su utilidad con el tiempo, este documento también considera la tasa de deterioro constante del producto. Además, para reducir el efecto del deterioro, muchos minoristas gastan dinero para preservar el producto. Este modelo también se ocupa de la preservación de la inversión en tecnología. El objetivo principal de este artículo de investigación es obtener un precio de venta óptimo, tiempo de ciclo e inversión en tecnología de preservación que maximice el beneficio total del minorista. Este modelo está respaldado por ejemplos numéricos y también reconoce el mejor escenario del modelo por resultados gráficos, en tres dimensiones. El análisis de sensibilidad de los principales parámetros se realiza para deducir las ideas de toma de decisiones.

PALABRAS CLAVE: Inventario; período de retraso permisible; demanda dependiente del tiempo sensible al precio; devolución del cliente; tasa constante de deterioro; tecnología de preservación.

1. INTRODUCTION

The expectable commercial dealings are created by cash-on-delivery. Nowadays, the commercial world has been motivated by giving credit periods to decide down the financial statement in contradiction of purchases. It is noticed that giving credit period will boost the demand and results in a decrease in stock. Goyal (1985) recognized an EOQ model with fixed upstream trade credits. Jamal *et al.* (2000) developed a retailer's model for the optimal cycle and payment times under the condition of permissible delay in payment. Chang *et al.* (2001) determined the optimal replenishment cycle by considering the varying rate of deterioration under permissible delay in payments. Jaggi *et al.* (2008) developed a new inventory model under two-level of trade credit. Shah *et al*. (2010) gave a review of quantitatively oriented approaches to determine the optimal lot size under the trade credit. Lou and Wang (2013) proposed an Economic order quantity model to determine the optimal trade credit under the impacts on both demand rate and default risk. Thereafter almost all researchers concluded that the demand rate is increased by the length of trade credit.

In this competitive world, strategic planning for return policy is considered a key problem in supply chain management for returning the product to retailers from customers. Chen and Bell (2009) Considered the customer's return product to the firm and addressed the simultaneous determination of price and inventory replenishment. Ghoreishi *et al.* (2013) studied the effect of inflation and customer returns on joint pricing by considering deteriorating items for inventory control. Hu and Li (2012) examined the return policies of the customer in a two-echelon supply chain that comprises an upstream supplier, a downstream retailer, and end consumers. He *et al.* (2006) developed a model and determined optimal return policies for single-period products based on uncertain market demands and in the presence of risk preferences. Pasternack (1985) considered the pricing decision faced by a procedure and developed a single period inventory model for examined the possible pricing and return policies for perishable commodities. Shah *et al.* (2019) assumed the demand which is fulfilled by using two substitutable items and considered the problem of inventory control for substitutable constant deteriorating items.

Harris (1913) was the first researcher who developed a basic EOQ model, in which demand was constant and not considered a deterioration item. In reality, the demand for some products like fashionable items, electronic items, and food items can be an increase or decrease with time. Considering this fact, Hariga (1996) established an EOQ model with time-dependent demand. Also, price owns a huge effect on demand. So, a general decrement in the selling price of some products will automatically increase customer demand, results in higher sales of such products. For example, pricing is an understandable policy to determine demand, written reports of some inventory models through price-dependent demand have received too much consideration into account. Shinn and Hwang (2003) determined the optimal ordering policy by considering price and order size simultaneously, in which the demand was the function of the selling price. Many of the researchers observed that there is some relation between demand rate and inventory level, they both are correlated with each other positively. Therefore, stock-dependent demand inventory models are also taken into consideration. Teng and Chang (2005) established an economic production quantity (EPQ) model in which demand was dependent on display stock level and selling price per unit. Shah *et al* (2017a) developed an EOQ model on optimum strategies and considered a price credit-dependent trapezoidal demand.

The above inventory model's interpretation of the results of price variations and conclusions of the optimum special-order quantity for the vendor. All the above researchers did not consider the perishable items (deteriorating inventory): which is a usual phenomenon. By keeping the deteriorating products like vegetables, juice, medicines, and fruits in storage for a long period, the products will damage with time. Thus, such types of products that are damaging because of deterioration cannot be ignored while determining the optimum order strategy. In the previous research, inventory-related problems of deteriorating items have been studied extensively. Ghare and Schrader (1963) was the first researcher who recognized a time-dependent inventory model for which demand was decreasing exponentially at a constant rate. After that Philip (1974) established an EOQ model and he considers the Weibull distribution deterioration rate with three parameters. Tripathi and Tomar (2015) studied the optimal setting up a strategy for deteriorating items with time-varying demand in response to an impermanent price discount related to order quantity, they considered a constant rate of deterioration. Shah *et al*. (2016) extended Tripathi and Tomar (2015) model and obtained an optimal ordering policy by considering quadratic demand with a constant rate of deteriorating items under the impact of the future price increase. Recently, Jani *et al*. (2020) discussed an EOQ model by considering the maximum lifetime of the products and variable demand.

Alternatively, to bring down the deterioration, Hsu *et al*. (2010) recognized an EOQ model and for minimizing the deteriorating rate of inventory, preservation technology investment has been taken into consideration with a constant rate of demand. Dye and Hsieh (2012) developed an inventory model and considered the replenishment schedule with the amount invested in preservation technology for the time-varying rate of deteriorating items. Shah *et al.* (2017b) developed an optimal ordering policy for time-varying deterioration items with preservation technology in which the demand was selling price-trade credit quadratic in nature. Recently, Chaudhari *et al.* (2020): discussed the inventory model for the early payment scheme and invested amount in preservation technology for perishable items.

The resulting flow of the article is governed as follows. Section 2 validates the notations and the assumptions that are applied. Section 3 is about the construction of a mathematical model of the inventory problem. Section 4 delivers an algorithm for checking the optimality of the total profit. Section 5 authorizes the resultant inventory model with numerical illustrations. The sensitivity analysis of the main parameters is held out in Section 6. Finally, Section 7 contains the conclusion of this article and its future possibilities.

2. NOTATION AND ASSUMPTIONS

Following notation and assumptions are used to build up the mathematical model of the problem under consideration.

2.1 Notation

A	Ordering cost per order ($/order)
C	Purchasing cost per unit ($/unit)
p	The selling price of the product ($/unit) (a decision variable) $(p > C)$
h	Inventory holding cost ($/unit/unit time)
θ	Constant Deterioration rate, $0 \le \theta \le 1$
a	Scale demand, $a > 0$
b	The linear rate of change of demand, $0 \le b < 1$
c	Quadratic rate of change of demand, $0 \le c < 1$
$R(p,t)$	Price-sensitive time-dependent demand
T	Cycle time (a decision variable) (in years)
M	Permissible delay period
I_e	Interest earned per $ per year
I_c	Interest charged per $ per year; $I_c > I_e$
u	Preservation technology investment ($/unit) (a decision variable)
$f(u)$	$= 1 - \dfrac{1}{1 + \mu u}$; the proportion of reduced deterioration item (in years)
$I(t)$	Inventory level at any time t; $0 \le t \le T$
Q	Ordering quantity (units/order)
$\pi(T, p, u)$	Retailer's total profit per unit time (in $)
*	The superscript denotes the optimal value

2.2 Assumptions

1. The scheme under review contracts with a single item.
2. The demand rate $R(p,t) = ap^{-\eta}(1+bt-ct^2)$ is a function of time and price p. Where a is known as a scale demand; $a > 0$, b denotes the linear rate of change of demand; $0 \le b < 1$ and c denotes the quadratic rate of change of demand; $0 \le c < 1$ and η is marked up for selling price.
3. Customers return $CR(p,t) = \alpha R(p,t) + \beta p$ $(\beta \ge 0, 0 \le \alpha < 1)$ (Chen and Bell (2009)) products during cycle time.
4. The planning horizon is infinite.
5. Shortages are not allowed.
6. Lead time is zero or negligible.
7. The retailer produces revenue by selling items and earns interest $[0, M]$ with the rate I_e.

8. When $M \le T$ the retailer would pay interest during $[M, T]$ the rate I_c for unsold stock.

9. The proportion of reduced deterioration rate, $f(u)$, is assumed to be a continuous increasing and concave function of investment u on preservation technology, i.e. $f'(u) > 0$, and $f''(u) > 0$. WLOG, assume $f(0) = 0$.

3. MATHEMATICAL MODEL

We analyze one inventory cycle. The following two situations are to be discussed (i) $M \le T$ (ii) $M > T$, for a given permissible delay period M, and also we derive the mathematical model for the supply chain by considering constant deteriorating items with preservation technology investment. The proportion of reduced deterioration rate $f(u)$ will take place when the buyer wishes to invest $'u'$ in the preservation technology. Hence, the rate of change of inventory level at any instant of time t is given by the following differential equation

$$\frac{dI(t)}{dt} = -R(t,p) - \theta(1 - F(u))I(t),\ 0 \le t \le T \tag{1}$$

According to the boundary condition, $I(T) = 0$, the solution of Equation (1) is given by

$$I(t) = \left(\frac{(\mu u+1)(2c\mu^2u^2 - 2c\mu t\theta u + ct^2\theta^2 + b\mu\theta u - bt\theta^2 + 4c\mu u - 2ct\theta + b\theta - \theta^2 + 2c)ap^{-\eta}e^{\frac{\theta t}{\mu u+1}}}{\theta^3} - \frac{(\mu u+1)(T^2c\theta^2 - 2Tc\mu\theta u + 2c\mu^2u^2 - Tb\theta^2 + b\mu\theta u - 2Tc\theta + 4c\mu u + b\theta - \theta^2 + 2c)ap^{-\eta}e^{\frac{\theta T}{\mu u+1}}}{\theta^3} \right) e^{\frac{-\theta t}{\mu u+1}} \tag{2}$$

Therefore, the order quantity is given by

$$Q = I(0) = \left(\frac{(\mu u+1)(2c\mu^2u^2 + b\mu\theta u + 4c\mu u + b\theta - \theta^2 + 2c)ap^{-\eta}}{\theta^3} - \frac{(\mu u+1)(T^2c\theta^2 - 2Tc\mu\theta u + 2c\mu^2u^2 - Tb\theta^2 + b\mu\theta u - 2Tc\theta + 4c\mu u + b\theta - \theta^2 + 2c)ap^{-\eta}e^{\frac{\theta T}{\mu u+1}}}{\theta^3} \right) \tag{3}$$

Now, the retailer's sales revenue per cycle time T for the product is given by $SR = p\int_0^T R(p,t)\,dt$

The cost components per cycle time T for the retailer can be comprised as follows.

•	Ordering cost per unit;	$OC = A$
•	Purchasing cost;	$PC = CQ$
•	Average holding cost per unit	$HC = h\int_0^T I(t)\,dt$
•	Customer Return cost;	$RC = p\int_0^T CR(p,t)\,dt$
•	Preservation technology investment;	$PT = uT$

Case-1: For $M \le T$

In this case, the permissible credit period M is less than or equal to the cycle time T.

The interest earned and an interest charge of the retailer $M \le T$ are shown in Figure 1.

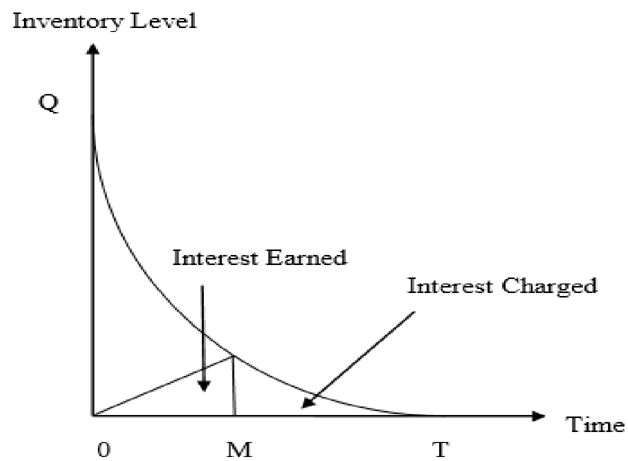

Figure 1. Interest earned and charged when $M \le T$ **(Shah *et al* 2015)**

From Figure 1., we can see that the buyer will earn interest at the rate I_e of the generated income during the time interval $[0, M]$. Hence, the interest earned per unit time is given by $IE_1 = pI_e \int_0^M t\, R(p,t)dt$

Now, during the time interval, $[M, T]$ the supplier will charge at the interest rate I_c for unsold stock.

Hence, the interest charged per unit time is $IC_1 = CI_c \int_M^T I(t)dt$

Hence, the total profit per unit time T for the retailer is given by

$$\pi_1(T, p, u) = \frac{1}{T}\left(SR - PC - OC - HC - RC + IE_1 - IC_1 - PT\right) \tag{4}$$

Case-2: $M > T$

In this case, the permissible credit period M is greater than the cycle time T.

The situation of the retailer $M > T$ is shown in Figure 2.

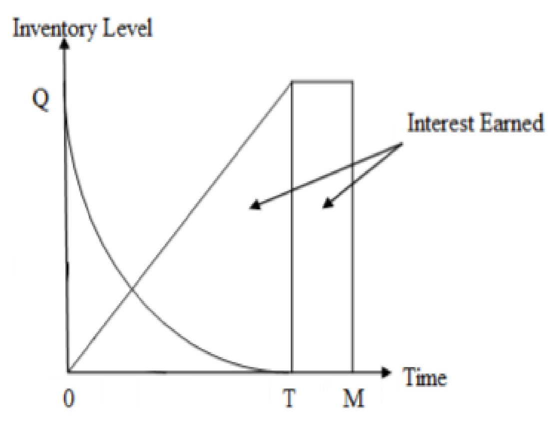

Figure 2. Interest earned when $M > T$ **(Shah *et al* 2015)**

From Figure 2. We can see that the retailer has sold all the purchased items before the credit period M

Therefore, Interest Charged; $IC_2 = 0$

Also, the retailer can earn interest during the time interval $[0, M]$ on the generated revenue at the rate I_c , which is given by Interest Earned $IE_2 = pI_e \int_0^T t \cdot R(p,t)dt + pI_e Q(M-T)$

Hence, the total profit per unit time T for the retailer is given by

$$\pi_2(T, p,u) = \frac{1}{T}(SR - PC - OC - HC - RC + IE_2 - IC_2 - PT) \quad (5)$$

Therefore, the total profit of the retailer can be given by

$$\pi(T, p,u) = \begin{cases} \pi_1(T, p,u); M \le T \\ \pi_2(T, p,u); M > T \end{cases}$$

Now, we will check the optimality of total profit with respect to decision variables by using the following algorithm.

4. ALGORITHM

For both cases, the total profit function is given by

$$\pi(T, p,u) = \begin{cases} \pi_1(T, p,u); M \le T \\ \pi_2(T, p,u); M > T \end{cases}$$

Here, this model adopts the following algorithm to check the optimality of decision parameters in mathematical software Maple $XVIII$.

Step 1: Apply the necessary conditions

$$\frac{\partial \pi(T, p,u)}{\partial p} = 0, \ \frac{\partial \pi(T, p,u)}{\partial T} = 0, \frac{\partial \pi(T, p,u)}{\partial u} = 0.$$

for finding the critical points T^*, p^* and u^* to making the total profit function minimum or maximum.

Step 2: Find all the possible second-order partial derivatives with respect to decision variables

$$\frac{\partial^2 \pi(T, p,u)}{\partial T^2}, \frac{\partial^2 \pi(T, p,u)}{\partial p \partial T}, \frac{\partial^2 \pi(T, p,u)}{\partial u \partial T} \frac{\partial^2 \pi(T, p,u)}{\partial T \partial p}, \frac{\partial^2 \pi(T, p,u)}{\partial p^2}, \frac{\partial^2 \pi(T, p,u)}{\partial u \partial p}, \frac{\partial^2 \pi(T, p,u)}{\partial T \partial u},$$

$$\frac{\partial^2 \pi(T, p,u)}{\partial p \partial u}, \frac{\partial^2 \pi(T, p,u)}{\partial u^2}$$

Step 3: Generate the Hessian Matrix

$$H\left(T^*, p^*, u^*\right) = \begin{bmatrix} \frac{\partial^2 \pi(T, p,u)}{\partial T^2} & \frac{\partial^2 \pi(T, p,u)}{\partial p \partial T} & \frac{\partial^2 \pi(T, p,u)}{\partial u \partial T} \\ \frac{\partial^2 \pi(T, p,u)}{\partial T \partial p} & \frac{\partial^2 \pi(T, p,u)}{\partial p^2} & \frac{\partial^2 \pi(T, p,u)}{\partial u \partial p} \\ \frac{\partial^2 \pi(T, p,u)}{\partial T \partial u} & \frac{\partial^2 \pi(T, p,u)}{\partial p \partial u} & \frac{\partial^2 \pi(T, p,u)}{\partial u^2} \end{bmatrix}$$

to obtain the concavity of the total profit function.

Step 4: Allocate hypothetical values to the inventory parameters in Hessian Matrix.

Step 5: Find Eigenvalues of Hessian Matrix $H\left(T^*, p^*, u^*\right)$

Step 6: According to Cardenas-Barron and Sana (2015): if all the eigenvalues of the Hessian matrix at the solution $\left(T^*, p^*, u^*\right)$ are positive, then the total profit function $\pi\left(T^*, p^*, u^*\right)$ has a minimum value at the solution and if all the eigenvalues are negative, then the total profit function $\pi\left(T^*, p^*, u^*\right)$ has a maximum value at the solution.

5. NUMERICAL EXAMPLES

Example: 1 Taking A = $115 per order , C = $ 20 per unit , h = $0.5/unit/year, a =4000units , b = 1% , c =12% , $\eta = 1.4$, $\alpha = 0.1$, $\beta = 0.1$, $I_c = 12\%$ /$/year, $I_e = 9\%$ /$/year, $\theta = 0.2$, $\mu = 1$ and $M = \frac{60}{365}$ year. The optimal cycle time $\left(T^*\right)$ is 1.320 years, the optimal retail price $\left(p^*\right)$ is $40.73, preservation technology investment $\left(u^*\right)$ is $6.54. Here $M \le T$. The retailer's purchase is 28.04 units and the eigenvalues of the Hessian matrix $H\left(T^*, p^*, u^*\right)$ are $-0.263, -0.866, -112.647$. Hence by the above algorithm, we can say that $\pi\left(T^*, p^*, u^*\right)$ has a maximum value and the corresponding profit is $50.84

Example: 2 Taking A = $115 per order , C = $ 20 per unit , h = $0.5/unit/year, a =4000units , b = 1% , c =12% , $\eta = 1.4$, $\alpha = 0.1$, $\beta = 0.1$, $I_c = 0\%$ /$/year, $I_e = 9\%$ /$/year, $\theta = 0.2$, $\mu = 1$ and $M = 1.3$ year. The optimal cycle time $\left(T^*\right)$ is 1.131 years, the optimal retail price $\left(p^*\right)$ is $39.207, preservation technology investment $\left(u^*\right)$ is $6.04. Here, $M > T$. The retailer's purchase is 25.80 units and the eigenvalues of the Hessian matrix $H\left(T^*, p^*, u^*\right)$ are $-0.280, -0.903, -187.785$. Hence by the above algorithm, we can say that $\pi\left(T^*, p^*, u^*\right)$ has a maximum value and the corresponding profit is $125.579

Note: - We do not consider such cases where the supplier may face loss whereas the retailer enjoys the profit during the product supply chain.

Example: 3 Taking A = $115 per order , C = $ 20 per unit , h = $0.5/unit/year, a =4000units , b = 1% , c =12% , $\eta = 1.4$, $\alpha = 0.1$, $\beta = 0.1$, $I_c = 12\%$ /$/year, $I_e = 9\%$ /$/year, $\theta = 0.2$, $\mu = 1$ and $M = 0$ year. The optimal cycle time $\left(T^*\right)$ is 1.330years, the optimal retail price $\left(p^*\right)$ is $41.05, preservation technology investment $\left(u^*\right)$ is 6.58. Here $M = 0$. The retailer's purchase is 27.91 units and the eigenvalues of the Hessian matrix $H\left(T^*, p^*, u^*\right)$ are $-2.263, -0.866, -112.647$. Hence by the above algorithm, we can say that $\pi\left(T^*, p^*, u^*\right)$ it has a maximum value and the corresponding profit is $42.23.

6. SENSITIVITY ANALYSIS

Now, for example 1, we observe the possible effects of numerous parameters on total profit, decision variables cycle time $\left(T\right)$, selling price $\left(p\right)$, and preservation technology investment $\left(u\right)$.

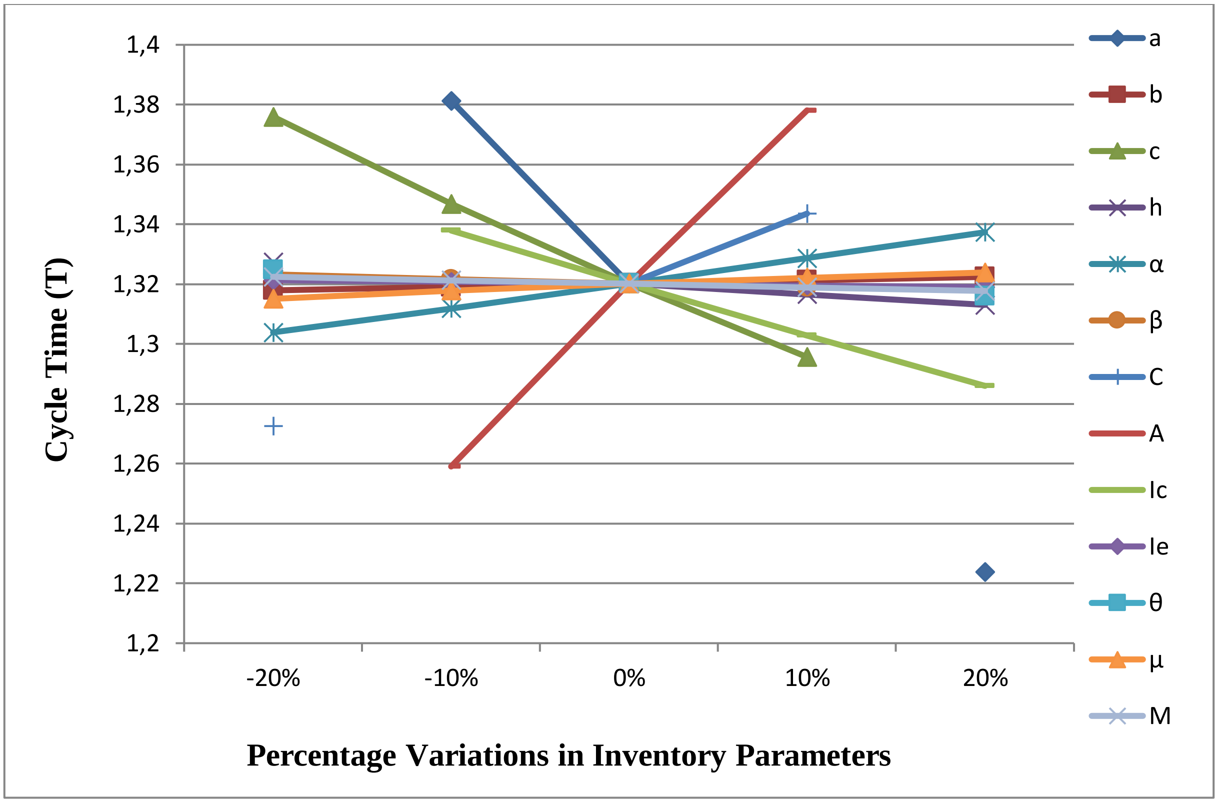

Figure 3. Variations in cycle time w. r. t. inventory parameters

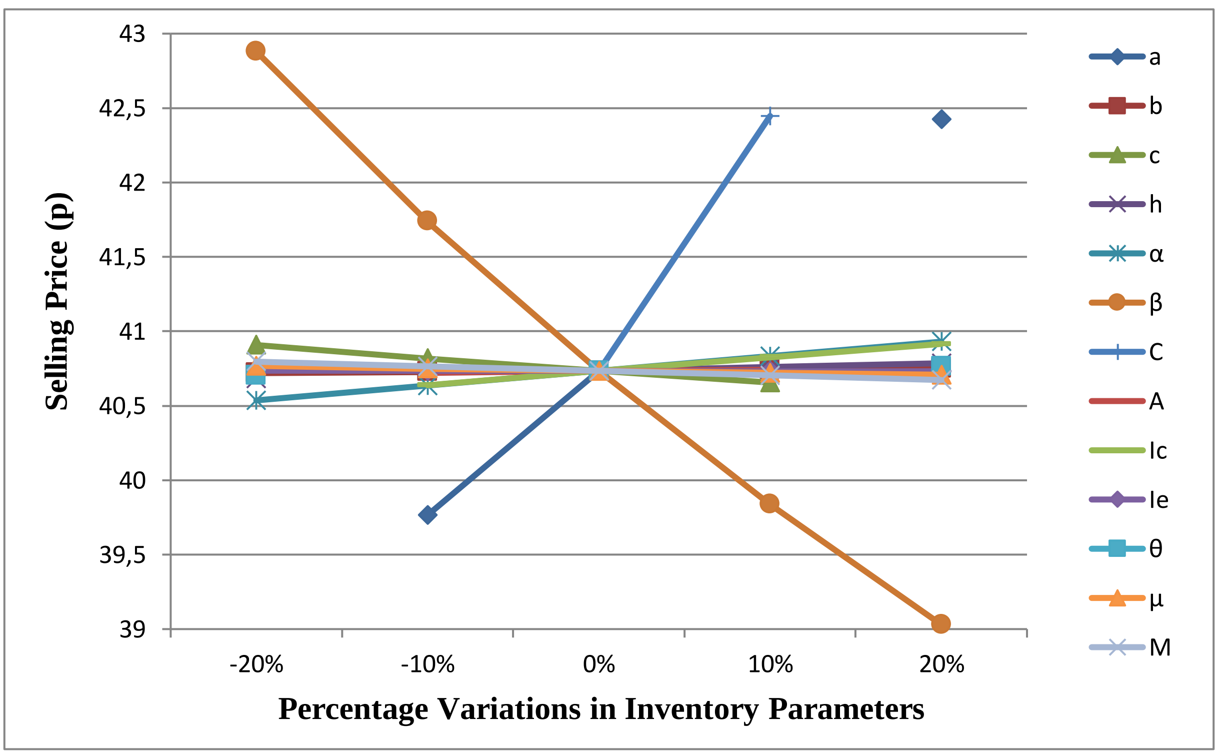

Figure 4. Variations in selling price w. r. t. inventory parameters

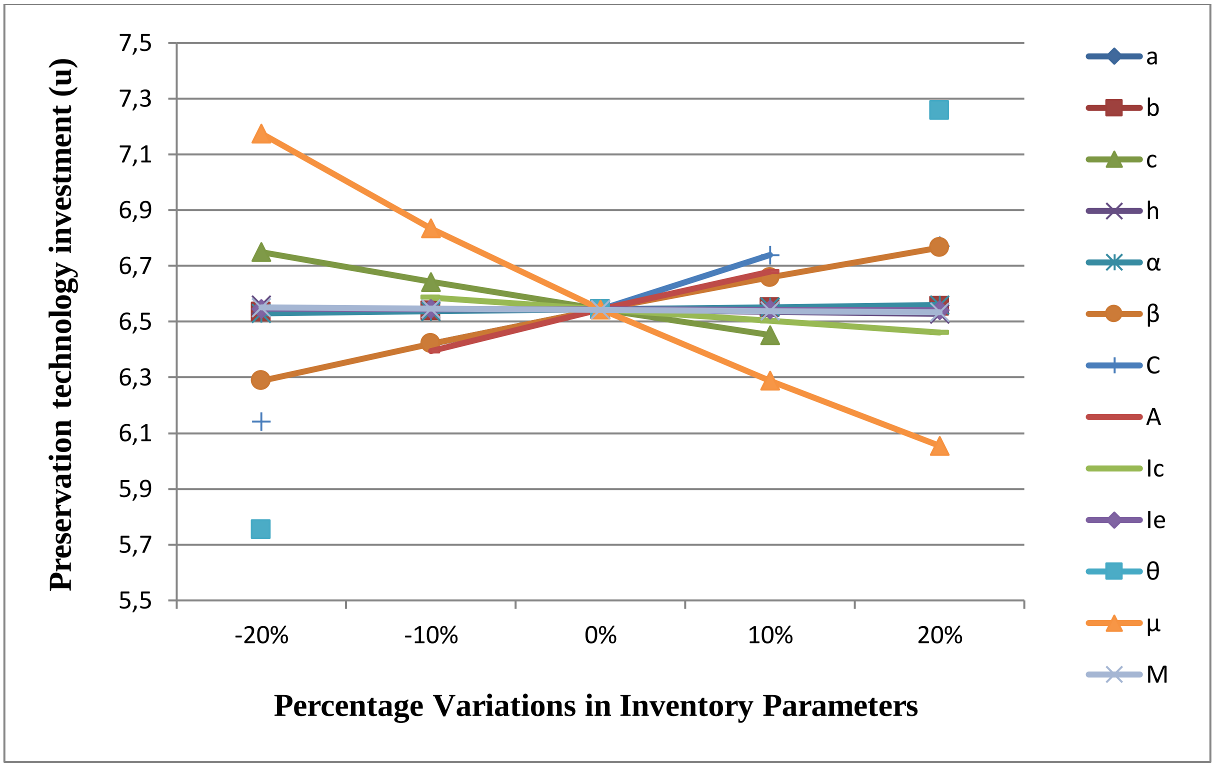

Figure 5. Variations in preservation technology investment w. r. t. inventory parameters

The observations from the above sensitivity analyses (Figures. 6-10) are as follows.

1. From Figure 3., it is evident that cycle time (T) has the positive effect of linear rate of change of demand (b), purchasing cost (C), ordering cost (A), and preservation parameter (μ), whereas cycle time (T) has the negative effect of scale demand (a), quadratic rate of change of demand (c), holding cost (h), interest charged for the unsold stock by the supplier (I_c), interest earned (I_e), deteriorating rate (θ) and credit period offered by a supplier to retailer (M).

2. From Figure 4., it is observed that selling price (p) has the positive effect of scale demand (a), the linear rate of change of demand (b), holding cost (h), purchasing cost (C), ordering cost (A), the interest charged for the unsold stock by the supplier (I_c), and deteriorating rate (θ) while selling price (p) has negative effect quadratic rate of change of demand (c), interest earned (I_e), preservation parameter (μ) and credit period by a supplier to retailer (M).

From Figure 5., it seems that preservation technology investment (u) has the positive effect of scale demand (a), the linear rate of change of demand (b), purchasing cost (C), ordering cost (A), and deteriorating rate (θ), whereas selling price has the negative effect of quadratic rate of change of demand (c), holding cost (h), interest charged for the unsold stock by the supplier (I_c), interest earned (I_e), preservation parameter (μ), credit period offered by a supplier to retailer (M).

7. CONCLUSIONS

To offer trade credit is the best promotional tool in the business world. In this paper, two different scenarios of trade credit are discussed where the supplier gives mutually agreed trade credit to the retailer. This paper also advocated the possible impact of customer returns during the replenishment time. To understand the realistic approach of the market the demand is considered as price dependent. The product deteriorates at a constant rate and preservation technology investment is considered to reduce the impact of deterioration. To describe the optimality of the decision parameters and total profit, three-dimensional graphs are plotted. The numerical evaluation of the model has been given to demonstrate the theoretical results. The sensitivity analysis is carried out to examine the changes in optimal solutions. From the sensitivity analysis, it is noticed that if scale demand increases the order quantity will also increase, and due to more units, the preservation of technology investment is also increased. Even though, it is advisable that if scale demand increases then the retailer can increase the selling price of the product which will increase the total profit. The present work can be extended by creating another realistic environment like stochastic demand, fuzzy demand, time-varying deterioration, two-layered trade credit, and shortages.

RECEIVED: JUNE, 2020.
REVISED: AUGUST, 2020.

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