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Replenishment Policy for Non instantaneous Deteriorating Items with Parabolic demand Pattern and partial backlogging for Queued Customers: Computational Approach

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Abstract

In this article an Inventory model for Non-Instantaneous deteriorating items for Queued Customers is developed under the assumption of partial backlogging. In the proposed model backlogging rate varies as the waiting time for the next replenishment. Demand follows Parabolicdem and pattern on time t. The model is fairly general due to dynamic nature of demand. When fresh and new items arrive in stock they begin to decay after a fixed time interval called the life period of items. For this kind of items the assumption that the deterioration starts from the instant of arrival in stock may cause retailer to make inappropriate replenishment policies due to over value the total annual relevant inventory cost. The main objective of this model is to minimize the total cost function with respect to optimal replenishment policy and time at which the shortage begins. We compute the optimal inventory period and total optimal average cost as most important performance measures for the model. Finally, numerical examples are provided to illustrate the problem and sensitivity analysis has been carried out to depict the significance of the total cost and the cycle period.

Keywords and Phrases: Partial backlogging, Non-instantaneous deterioration, Parabolic demand and Queued Customers.

1. INTRODUCTION

The study of effect of deteriorating items in inventory models becoming growing interest since last two decade. Due to this, we can make the proper planning to maintain the inventory economically to increase the revenue of industry. Deteriorating items can be classified into two categories. The first category refers to the items that become decayed, damaged, evaporative, expired, invalid, devaluation and so on through time like meat, vegetables, fruit, medicine, flowers, film and so on; the other category refers to the items that lose part or total value through time because of new technology or the introduction of alternatives, like computer chips, mobile phones, fashion and seasonal goods, and so on. Both the two categories have the characteristic of short life cycle.

Shah and Jaiswal (1977) proposed an order-level inventory model for items with a constant rate of deterioration. Aggarwal (1978), Dave and Patel (1981), Giri and Chaudiri (1988), Chang and Dye (1999), Khanra and Chaudhuri (2003), Teng, Chang and Goyal (2005) have used constant deterioration rate in inventory models. Anil kumar Sharma et al. (2012) considered an inventory model with time dependent holding cost. Chaitanya Kumar Tripathy and Umakanta Mishra (2010) developed an inventory model for Weibull deteriorating items for quadratic demand with permissible delay in payments. R. Begum, S.K.Sahu and R.R.Sahoo (2010) established an order level inventory models for deteriorating items with quadratic demand. Gobinda Chandra et al. (2012) analysed constant deteriorating inventory management with quadratic demand rate. R. Begum, S.K.Sahu and R.R.Sahoo (2012) developed an inventory model for deteriorating with quadratic demand and partial backlogging. Trailokyanth Singh and HadibandhuPattanayak (2013) presented an EOQ model for a deteriorating item with time dependent quadratic demand and variable deterioration under delay in payments. Recently, Venkateswarlu. R and Mohan.R (2014) studied an inventory model with Weibull deterioration and quadratic demand under inflation. In this paper, we have taken deterioration rate as constant and demand rate is quadratic function of time. Shortages are not allowed and time dependent holding cost.

In practice it can be observed that constant rate of deterioration occurs rarely. Most of the items deteriorate fast as the time passes. Therefore, it is much more realistic to consider the deterioration rate. In a realistic product life cycle, demand is increasing with time during the growth phase.[9] investigated an inventory system with power demand pattern for items with variable rate of deterioration. [3] studied the inventory system with two-parameter exponential distributed hazardous items in which production and demand rate were constant.[21] considered an EOQ model in which inventory is depleted not only by demand, but also by deterioration at a Weibull distributed rate, assuming the demand rate with a ramp type function of time. [10] developed an inventory model for a deteriorating item having an instantaneous supply, a quadratic time-varying demand and shortages in inventory. They had taken a two-parameter Weibull distribution to represent the time to deterioration.[15] considered an inventory model for deteriorating items in which demand increases with respect to time, deterioration rate, inventory holding cost and ordering cost are all continuous functions of time. Shortages are completely backlogged. The planning horizon is finite.

[16] formulated an order-level lot-size inventory model for a time-dependent deterioration and exponentially declining demand.[14] reviewed the recent studies about the deteriorating items inventory management research status. They provided a comprehensive introduction, compared with

the extant reviews and proposed some key factors which should be considered in the deteriorating inventory studies. This survey provides a clear overview of the deteriorating inventory study field, which can be used as a starting point for further study. A key assumption of the basic EOQ model is that stock outs are not permitted. Relaxing the basic EOQ that stock outs are not permitted led to the development of EOQ model for the two basic stock out cases: backorders and lost sales. What took longer to develop was a model that recognized that, while some customers are willing to wait for delivery, others are not. Either these customers will cancel their orders or the supplier will have to fill them within the normal delivery time by using more expensive supply methods. While there have been a number of models developed for the EOQ model with partial backordering, most of them incorporate considerably more complicated assumption sets than the classic EOQ model do. Furthermore, when the shortage occurs, some customers are willing to wait for back order and others would turn to buy from other sellers.

There are a number of situations in which a customers or vendors of some sort are assumed to receive the demand in bulk of inventory are subject to put in queue at a service facility. The goal of queuing is essentially to trade-off the cost of providing a level of service capacity and the customers waiting for service.

With this motivation, in the present paper an attempt is made to formulate a partial backlogging inventory model by incorporating the deterioration effect and time-dependent parabolic pattern demand rate. Deterioration of items begins after a certain time from the instant of their arrival in stock, we name it as life time of items. Unsatisfied demand is partially backlogged with a variable rate. To suit present day competition in the market, the backlogging rate is inversely proportional to the duration of waiting time up to arrival of next lot. The differential equations are derived and the instantaneous state of inventory is obtained analytically. The total cost function, which consists of setup cost, holding cost, backordering cost, lost sale cost (Opportunity cost), deterioration cost, waiting cost and procurement cost is constructed and subjected to the optimization which in turn gives us the system of non linear equations. Further, a computing algorithm is proposed to find the solution of the system by using the N-R method. We compute the optimal inventory period and total optimal average cost as most important performance measures for the model. Numerical demonstration and sensitivity analysis have been carried out for the model to identify the most sensibilities of various parameters involved in the system leading to interesting observations which seem to be consistent with its economic insights. This model is much useful for analysing the planning of the seasonal and fashionable products with the notion of decay or obsolete.

2. ASSUMPTIONS AND NOTATIONS

In this paper we have made the following notations and assumptions in the formulation of proposed mathematical model of the inventory system.

1 . The consumption rate D(t) (for parabolic demand)at time it is assumed to be

$$D(t) = \begin{cases} a + bt + ct^2, 0 \le t \le t_d, t_d \le t \le t_1 \\ B, \qquad t_1 \le t \le T \end{cases},$$

where a is a positive constant, b, c are the time-dependent consumption rate parameter, $0 \le b, c \le 1$.

2. The replenishment rate is infinite and lead time is zero.
3. Shortages are allowed and the backlogged rate is defined to be $\frac{1}{1+\delta(T-t)}$ when inventory is negative. The backlogging parameter δ is a positive constant.
4. It is assumed that during certain period of time the product has no deterioration (i.e., fresh product time).After this period, a fraction, θ (0<θ<1), of the on-hand inventory deteriorates.
5. Product transactions are followed by instantaneous cash flow.
6. λ and μ are assumed to be constant and are related by $L_S = \left(\frac{\lambda}{\mu - \lambda}\right)$

The following notations are used:

K	-	Ordering cost of inventory, $ per order.
$I(t)$	-	The inventory level at time t.
θ	-	Deterioration rate, a fraction of the on-hand inventory
p	-	Purchase cost, $ per unit
h	-	Holding cost excluding interest charges, $ per unit/ year.
s	-	Shortage cost, $ per unit/year
π	-	Opportunity cost due to lost sales, $ per unit
T	-	The length of replenishment cycle.
t_d	-	The length of time in which the product has no deterioration (Fresh product)
t_1		Time at which shortages starts, $0 \le t_1 \le T$.
I_m	-	Maximum Inventory level.
I_b	-	Maximum amount of shortage demand to be backlogged.

λ - The Average arrival rate

μ - The Average Service rate

L_S - The number of customers waiting for inventory

C_W - Waiting cost per customer per unit time

C_P - Procurement cost

$TAC(t_1^-)$ The average total inventory cost per unit time.

3. MODEL FORMULATION

The inventory system evolves as follows: I_m units of items arrive at the inventory system at the beginning of each cycle. During the time interval $[0, t_d]$, the inventory level is decreasing only owing to demand rate. The inventory level is dropping to zero due to demand and deterioration during the time interval $[t_d, t_1]$. Then the shortage interval keeps to the end of the current order cycle. The whole process is repeated.

Based on the above description, the differential equation representing the inventory status is given by

$$\frac{dI(t)}{dt} = \begin{cases} -(a+bt+ct^2) & 0 \le t \le t_d, \\ -(a+bt+ct^2) - \theta I_2(t) & t_d \le t \le t_1, \\ \dfrac{-B}{1+\delta(T-t)} & t_1 \le t \le T \end{cases} \quad ..(1)$$

With the boundary conditions $I(0) = I_m$, $I(t_1)=0$.

The solution of Eq.(1) is

$$I(t) = \begin{cases} I_1(t) & if \quad 0 \le t \le t_d, \\ I_2(t) & if \quad t_d \le t \le t_1, \\ I_3(t) & if \quad t_1 \le t \le T, \end{cases}$$

$$\frac{dI_1(t)}{dt} = -(a+bt+ct^2) \quad 0 \le t \le t_d \quad (2)$$

$$\frac{dI_2(t)}{dt} + \theta I_2(t) = -(a+bt+ct^2) \quad t_d \le t \le t_1 \quad (3)$$

$$\frac{dI_3(t)}{dt} = \frac{-B}{1+\delta(T-t)} \quad t_1 \le t \le T \quad .....(4)$$

Solution of (2), (3), (4) is given by

$$I_1(t) = -\left(at + \frac{bt^2}{2} + \frac{ct^3}{3}\right) + I_m, \quad 0 \le t \le t_d \quad ....(5)$$

$$\begin{aligned} I_2(t) = &\left(\frac{2c}{\theta^3} - \frac{b}{\theta^2} + \frac{a}{\theta}\right)\left(e^{\theta t_1} - e^{\theta t}\right) \\ &+ \left(\frac{b}{\theta} - \frac{2c}{\theta^2}\right)\left(t_1 e^{\theta t_1} - t e^{\theta t}\right) \\ &+ \frac{c}{\theta}\left(t_1^2 e^{\theta t_1} - t^2 e^{\theta t}\right) \qquad t_d \le t \le t_1 \end{aligned} \quad (6)$$

$$I_3(t) = \left\{\frac{-B}{\delta}\begin{bmatrix} \log(1+\delta(T-t_1)) \\ -\log(1+\delta(T-t)) \end{bmatrix}\right\}, \quad t_d \le t \le t_1 \quad (7)$$

Considering the continuity of $I(t)$ at $t = t_d$ it follows that $I_1(t_d) = I_2(t_d)$ which implies that

$$\begin{aligned} I_m = &at_d + \frac{bt_d^2}{2} + \frac{ct_d^3}{3} + \left(\frac{2c}{\theta^3} - \frac{b}{\theta^2} + \frac{a}{\theta}\right)\left(e^{\theta t_1} - e^{\theta t_d}\right) \\ &+ \left(\frac{b}{\theta} - \frac{2c}{\theta^2}\right)\left(t_1 e^{\theta t_1} - t_d e^{\theta t_d}\right) + \frac{c}{\theta}\left(t_1^2 e^{\theta t_1} - t_d^2 e^{\theta t_d}\right) \end{aligned}$$

Therefore,

$$\begin{aligned} I_1(t) = &\left(a(t_d - t) + \frac{b(t_d^2 - t^2)}{2} + \frac{c(t_d^3 - t^3)}{3}\right) \\ &+ \left(\frac{2c}{\theta^3} - \frac{b}{\theta^2} + \frac{a}{\theta}\right)\left(e^{\theta t_1} - e^{\theta t_d}\right) + \left(\frac{b}{\theta} - \frac{2c}{\theta^2}\right)\left(t_1 e^{\theta t_1} - t_d e^{\theta t_d}\right) \\ &+ \frac{c}{\theta}\left(t_1^2 e^{\theta t_1} - t_d^2 e^{\theta t_d}\right), \qquad 0 \le t \le t_d \end{aligned}$$

The maximum backlogging quantity is given by

$$I_3(T) = I_b$$

The order quantity is given by

$$Q = I_m + I_b \quad .....(8)$$

The total average inventory cost per cycle consist of the following elements.

(a) The cost of placing orders per cycle is K

(b) The inventory holding cost HC per cycle is given by

$$HC = h\int_0^{t_d} I_1(t)dt + h\int_{t_d}^{t_1} I_2(t)dt$$

$$\begin{aligned} HC = {} & \frac{h}{\theta^4} e^{\theta t_d}\left(\theta^3\left(-t_d^{\,2}b - t_d a - ct_d^{\,3}\right) + \theta^2\left(2bt_d + 3ct_d^{\,2} + a\right) + \theta\left(-6ct_d - 2b\right) + 6c\right) \\ & + \frac{h}{\theta^4} e^{\theta t_1}\left(\theta^3\left(t_1^{\,2}b + t_1 a + ct_1^{\,3}\right) + \theta^2\left(-2bt_1 - 3ct_1^{\,2} - a\right) + \theta\left(6ct_1 + 2b\right) - 6c\right) \\ & + \frac{ht_d^{\,2}}{12}\left(3ct_d^{\,2} + 4bt_d + 6a\right) \end{aligned} \qquad \text{……...(9)}$$

(c) The deterioration cost per cycle DC is given by

$$\text{DC} = p\theta\int_{t_d}^{t_1} I_2(t)dt$$

$$\begin{aligned} DC = {} & \frac{6pc}{\theta^3}\left(e^{\theta t_d} - e^{\theta t_1}\right) + \frac{p}{\theta^2}\left(e^{\theta t_1}\left(6ct_1 + 2b - 2ct_d\right) - e^{\theta t_d}\left(2b + 4ct_d\right)\right) \\ & - \frac{p}{\theta}\left(e^{\theta t_1}\left(a + 2bt_1 - bt_d + 3ct_1^{\,2} - 2ct_d t_1\right) - e^{\theta t_d}\left(bt_d + ct_d^{\,2} + a\right)\right) \\ & - p\left(e^{\theta t_1}\left(bt_d t_1 + at_d - bt_1^{\,2} - ct_1^{\,3} - at_1 + ct_d t_1^{\,2}\right)\right) \end{aligned} \qquad \text{……..(10)}$$

(d) The shortage cost per cycle SC is given by

$$\text{SC}= s\int_{t_1}^{T} -I_3(t)dt$$

$$SC = sB\left(\frac{\delta(T-t_1) - \log(1+\delta(T-t_1))}{\delta^2}\right) \qquad \text{……..……(11)}$$

(e) The opportunity cost per cycle due to lost sales OC is given by

$$\text{OC}= \pi\int_{t_1}^{T}\left(\alpha - \frac{\alpha}{1+\delta(T-t)}\right)dt$$

$$OC = \pi B\left(\frac{\delta(T-t_1) - \log(1+\delta(T-t_1))}{\delta}\right) \qquad \text{…….(12)}$$

The Total waiting cost for the customers in the system

$$WC = C_W L_S = C_W\left(\frac{\lambda}{\mu-\lambda}\right) \qquad \text{..……..…….(13)}$$

The Total Procurement cost for the system

$$PC = C_P I_m \qquad \text{…….(14)}$$

Thus the total average cost of the system per unit time is given by

$$TAC(t_1) = \frac{K + HC + DC + SC + OC + PC + WC}{T} \qquad \text{…….(15)}$$

$$= \frac{1}{T}\left\{\begin{array}{l} K + \frac{h}{\theta^4} e^{\theta t_d}\left(\theta^3\left(-t_d^{\,2} b - t_d a - c t_d^{\,3}\right) + \theta^2\left(2bt_d + 3ct_d^{\,2} + a\right) + \theta\left(-6ct_d - 2b\right) + 6c\right) \\ + \frac{h}{\theta^4} e^{\theta t_1}\left(\theta^3\left(t_1^{\,2} b + t_1 a + c t_1^{\,3}\right) + \theta^2\left(-2bt_1 - 3ct_1^{\,2} - a\right) + \theta\left(6ct_1 + 2b\right) - 6c\right) + \frac{h t_d^{\,2}}{12}\left(3ct_d^{\,2} + 4bt_d + 6a\right) \\ + \frac{6pc}{\theta^3}\left(e^{\theta t_d} - e^{\theta t_1}\right) + \frac{p}{\theta^2}\left(e^{\theta t_1}\left(6ct_1 + 2b - 2ct_d\right) - e^{\theta t_d}\left(2b + 4ct_d\right)\right) - \frac{p}{\theta}\left(e^{\theta t_1}\left(a + 2bt_1 - bt_d + 3ct_1^{\,2} - 2ct_d t_1\right) - e^{\theta t_d}\left(bt_d + ct_d^{\,2} + a\right)\right) \\ - p\left(e^{\theta t_1}\left(bt_d t_1 + at_d - bt_1^{\,2} - ct_1^{\,3} - at_1 + ct_d t_1^{\,2}\right)\right) + sB\left(\frac{\delta(T - t_1) - \log(1 + \delta(T - t_1))}{\delta^2}\right) + \pi B\left(\frac{\delta(T - t_1) - \log(1 + \delta(T - t_1))}{\delta}\right) \\ + C_P\left(at_d + \frac{bt_d^{\,2}}{2} + \frac{ct_d^{\,3}}{3} + \left(\frac{2c}{\theta^3} - \frac{b}{\theta^2} + \frac{a}{\theta}\right)\left(e^{\theta t_1} - e^{\theta t_d}\right) + \left(\frac{b}{\theta} - \frac{2c}{\theta^2}\right)\left(t_1 e^{\theta t_1} - t_d e^{\theta t_d}\right) + \frac{c}{\theta}\left(t_1^{\,2} e^{\theta t_1} - t_d^{\,2} e^{\theta t_d}\right)\right) + C_W\left(\frac{\lambda}{\mu - \lambda}\right) \end{array}\right\}$$

……(16)

To minimize total average cost per unit time

Equation (16) is a non-linear equation in t_1 and its value is obtained by using Maple provided total cost is minimum and its second derivative is positive.

4. NUMERICAL EXAMPLES

To illustrate the preceding theory the following examples are presented.

Example:

Let K =500 per order, P=120 per unit, h=10 per unit per year, t_d =0.08, s=40 per unit,θ=0.06, a=5,b=20,c=0.5, π =10 per unit,δ =0.56, B=400, $\lambda = 10, \mu = 8$, $C_W = 5, C_P = 6$,T=1 year

SENSITIVITY ANALYSIS

Table 1: Effect of Inventory and Optimal Average Total Cost function with respect to t_d

t_d	% in Change	Inventory Period t_1	Initial Inventory Level I_m	Optimal Average Total Cost TAC
0.048	-40	0.7420	80.5046	2199.1947
0.064	-20	0.7421	78.8961	2190.4738
0.080	0	0.7422	77.2868	2179.5960
0.096	+20	0.7423	75.6765	2166.5632
0.112	+40	0.7424	74.0653	2151.3675

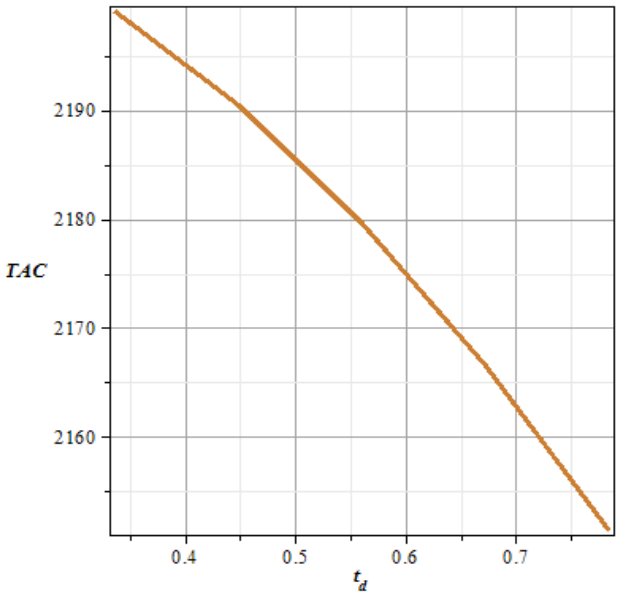

Figure 1: Effect of t_d on Optimal Average Total Cost function (Parabolic Demand)

Table 2: Effect of Inventory and Optimal Average Total Cost function with respect to δ

δ	% in Change	Inventory Period t_1	Initial Inventory Level I_m	Optimal Average Total Cost TAC
0.336	-40	0.7333	76.1842	2148.7956
0.448	-20	0.7378	76.7446	2164.4574
0.560	0	0.7422	77.2868	2179.5960
0.672	+20	0.7464	77.8116	2194.2400
0.784	+40	0.7505	78.3200	2208.4120

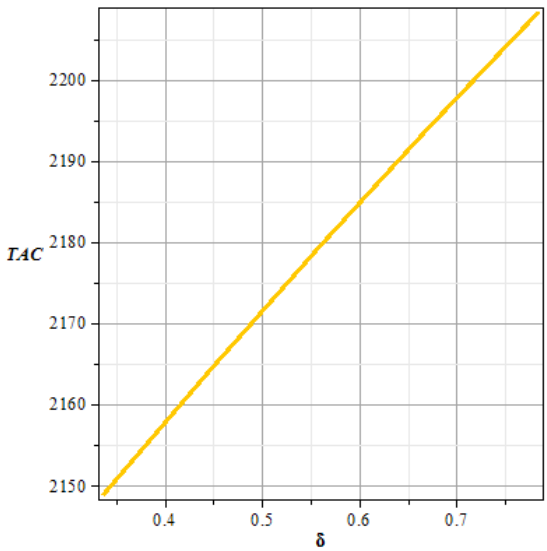

Figure 2: Effect ofδon Optimal Average Total Costfunction (Parabolic Demand)

Table 3: Effect of Inventory and Optimal Average Total Cost function with respect to θ

θ	Inventory Period t_1	Initial Inventory Level I_m	Optimal Average Total Cost TAC
0.056	0.7603	55.6711	1973.8278
0.058	0.7491	67.2941	2097.5042
0.060	0.7422	77.2868	2179.5960
0.062	0.7384	86.0116	2230.5541
0.064	0.7369	93.7226	2257.7472

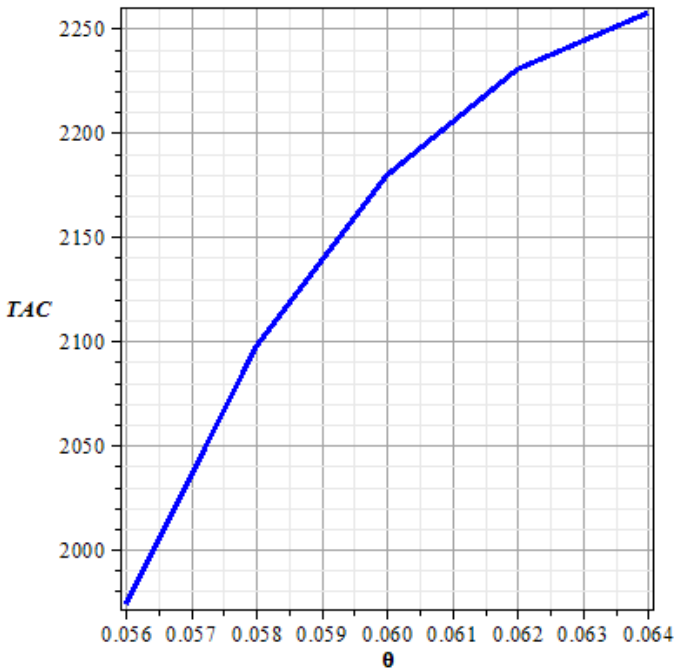

Figure 3: Effect of Inventory and Optimal Average Total Cost function with respect to θ

Table 4: Effect of Inventory and Optimal Average Total Costfunction with respect to C_W

C_W	% in Change	Inventory Period t_1	Initial Inventory Level I_m	Optimal Average Total Cost TAC
3	-40	0.7422	77.2868	2189.5960
4	-20	0.7422	77.2868	2184.5960
5	0	0.7422	77.2868	2179.5960
6	+20	0.7422	77.2868	2174.5960
7	+40	0.7422	77.2868	2169.5960

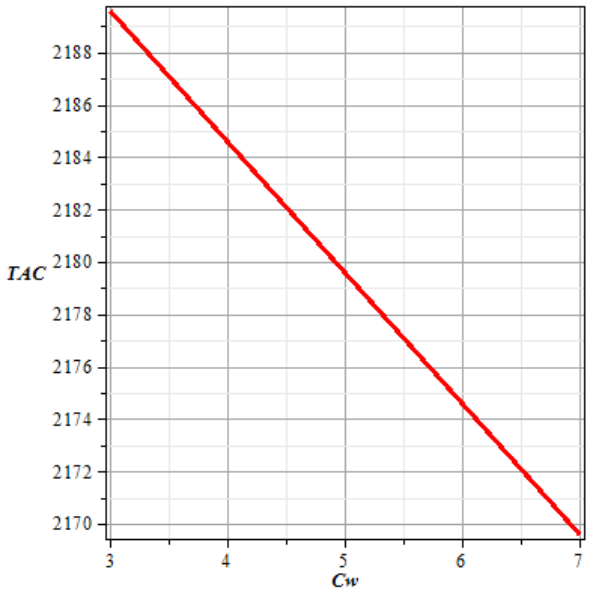

Figure 4: Effect of$C_W$on Optimal Average Total Cost function (Parabolic Demand)

Table 5: Effect of Inventory and Optimal Average Total Cost function with respect to C_P

C_P	% in Change	Inventory Period t_1	Initial Inventory Level I_m	Optimal Average Total Cost TAC
3.6	-40	0.8154	86.4493	1468.7492
4.8	-20	0.7770	81.6235	1841.2959
6.0	0	0.7422	77.2868	2179.5960
7.2	+20	0.7105	73.3657	2488.2763
8.4	+40	0.6816	69.8013	2771.1455

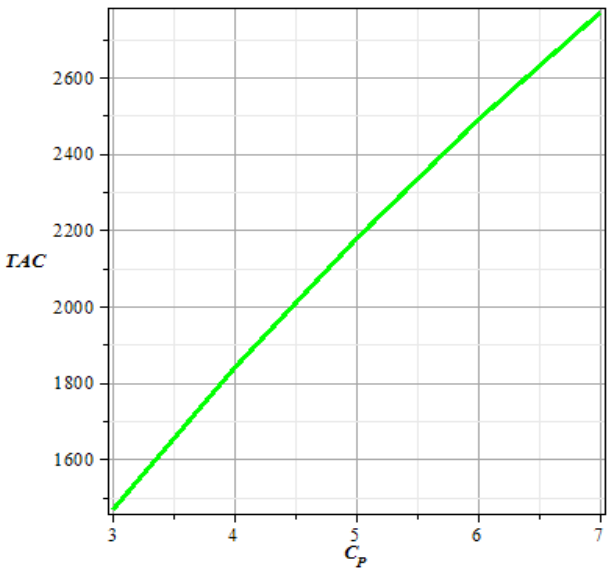

Figure 5: Effect of$C_P$onOptimal Average Total Cost function (Parabolic Demand)

5. MANAGERIAL IMPLICATIONS

Based on the numerical examples considered above we now study the effects of change in t_d, δ,θ, C_W and C_P on the optimal values of t_1 and Total average cost.

The results are summarized above. Based on, the observations can be made as follows:

1. When the fresh product time t_d increases, the initial inventory and the Optimal Average Total Cost decreases. That is, the longer the fresh product time is, the lower total cost would be. It implies that the model with non-instantaneous deteriorating item always has smaller total annual inventory cost than instantaneous items. If the retailer can extend effectively the length of time the product has no deterioration for few days or months the total cost, order quantity reduced obviously.
2. Increasing the backlogging parameter δ or equivalently increasing the backlogging rate increases initial inventory and increases the Optimal Average Total Cost. It implies that the retailer should restrict the backlogging parameter with the aim of reducing the average total inventory cost.
3. When the deterioration rate θ is increasing, the Optimal Average Total Cost is increasing and the initial inventory is increasing.
4. When waiting cost increases, the other parameters remain unchanged, and the optimal Average Total Cost decreases.
5. In Table 5 and Figure 5, we find that as the Procurement Cost increases, the optimal total average cost also increases and initial inventory level decreases.

Hence if the retailer can effectively reduce the deteriorating rate of an item by improving equipment of store house, the total annual inventory cost will be lowered.

8. CONCLUSION

The main purpose of this study is to frame a suitable model that will help the retailer to determine the optimal replenishment policy for non-instantaneous deteriorating items, with parabolic demand for queued customers. This model will suits to situations where shortages were allowed (Partially Backlogged). Behaviour of different parameters have been discussed through the numerical example and sensitivity analysis. From sensitivity analysis carried out some managerial insights are obtained. The retailer can reduce total annual inventory cost, when by improving storage conditions for non-instantaneous deteriorating items and increasing backlogging rate (or equivalently decreasing the backlogging parameter).

Thus, this model incorporates some realistic features that are likely to be associated with some kinds of inventory. The model is very useful in the retail business. It can be used for electronic components, fashionable clothes, domestic goods and other products which are more likely with the characteristics above.

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