International Journal of Engineering, Science and Mathematics
Vol. 6 Issue 1, March 2017,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

An inventory model for deteriorating items with time dependent demand under preservation technology and shortages under trade credit

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ABSTARCT
In this paper we have developed an inventory model with variable demand and holding cost under shortages. Further we have studied the effect of preservation technology on deterioration rate under the effect of trade credit. In the second section, assumptions and notation are given for mathematical model formulation which elaborated in the third section. Numerical illustration and sensitivity analysis is mentioned in fourth and fifth sections respectively. We have concluded our model in the sixth section.

Key Words: preservation technology and shortages

1 INTRODUCTION

In literature deterioration rate is considered as a uncontrolled variable but in realistic situations deteriorating nature can be controlled up to a certain level. It is only possible through the preservation techniques. Due to its implications as well as public and environment changes preservation techniques becomes very important in deteriorating inventory systems. Lee and Dye (2012) has been studied the effect of preservation. Mishra (2013) is another who has integrated the model of preservation technology investment for deteriorating inventory. Ghare and Schrader (1963) first developed the concept of deterioration. Hariga et al. [1994] considering exponentially increasing and decreasing demand. Chu and Chen (2001) considered a model for deteriorating items with time-varying demand. Singh and Jain (2008) explored an inventory model for a deteriorating item under the effect of inflation. Tripathy and Pradhan (2011) presented a model having weibull demand and variable deterioration rate with the effect of trade credit under partial backlogging. Singh and Singh (2011) developed an imperfect production model with exponential demand rate, Weibull deterioration under inflationary conditions. Sharma and Chaudhary (2013) derived a model with weibull deterioration with time dependent demand and shortages.

Due to excess demand stock level reaches at zero. In such situation suppliers try to maintain the customers for this they have considered the partially backlogged shortages. Many researchers have been discussed the concept of shortages like Singh and Singh (2007), Singh, et. al. (2010), Hung (2011), Pentico and Drake (2011), Taleizadch and Pentico (2013), Ghiami, et. al. (2013) etc.

To solve the economic order quantity (EOQ) formula, it is considered that the trader must be paid for the items as soon as the items are received. On the other hand, a supplier will permit a certain fixed period for settling the amount owed to him for the items supplied. Generally there is no charge if the outstanding amount is settled within the permitted fixed settlement period. Beyond this period, interest is charged. When a supplier permits a fixed time period for settling the account, he is actually giving a loan to his customer without any interest during this period. During the period before the account has to be settled, the customer can sell the items and continue to accumulate the profit and earn interest instead of paying off the overdraft which is necessary if the supplier requires settlement of the account instantly after replacement. Therefore, it makes economic sense for the customer to delay the settlement of the replenishment account up to the last moment of the permissible period allowed by the supplier. To attract more customers supplier gives a period to settle the account i.e. permissible delay in payment. After this period an interest is charged on unsold items. For literature review we can go through the work of researchers like Teng, et. al. (2005), Kumari, et. al. (2008), Kumar, et. al. (2008), Chang, et. al. (2009), Chen and Kang (2010), Chen and Cheng (2011), Jaggi, et. al. (2011), Singh, et. al. (2011), Zhou, et. al. (2012) and Yadav, et. al. (2013) etc.

4.2 ASSUMPTIONS and NOTATIONS

We have used following assumptions and notations for the formulation of mathematical model.

Assumptions

(1) The demand is treated as linear function of time as follows

$$D(t) = \alpha + \beta t;\ \alpha > 0,\ \beta > 0.$$

(2) Partially backlogged shortages are permitted.

(3) Holding cost is time varying i.e. $h(t) = h_1 + h_2 t$, where $h_1, h_2 > 0$

(4) Replenishment is instantaneous.

(5) Lead time is zero

(6) Preservation Technology is used to reduce deterioration rate.

(7) Deterioration rate is constant

(8) Suppliers permit delay (M) in payment to a purchaser, during this period purchaser deposits their revenue in a interest bearing account. At the end of delay period they have two choices that is they can pay the amount at the end of delay period or after the delay period (payment time between M and T_1). Supplier charges high interest for unsold times when purchaser choose the payment time (K) between M and T_1.

Notations

A: The unit ordering cost

p: The unit selling price

C: The unit purchasing cost

C_1: The unit backorder cost

C_2: The unit lost sale cost

h (t): The time varying holding cost excluding interest charges

θ: The deterioration rate.

M (ξ): Reduced deterioration rate due to use of Preservation Technology and

$m(\xi) = \theta(1 - e^{-a\xi})$ where $a>0$.

ξ :Preservation Technology (PT) cost to preserve the product through which deterioration rate is also reduced $\xi > 0$.

τ_P: Resultant Deterioration rate, $\tau_P = (\theta - m(\xi))$.

r: constant represents the difference between discount rate and inflation rate, where $0 \le r < 1$.

I_e: interest earned per $ per year.

I_p: Interest paid by purchaser per $ in stock per year, which is charged by supplier.

M: Permissible delay in payment (i. e. trade credit for purchaser to settle the account).

K: Payment time

T: The length of cycle time.

T_1: The time at which shortages occurs.

$I_1(t)$: Inventory level during time period $[0, T_1]$.

$I_2(t)$: Inventory level during time period $[T_1, T]$.

Q: IM+IB, The order quantity during cycle length [0, T].

IM: Maximum inventory level during cycle time $[0, T_1]$.

IB: Maximum inventory level during shortage period $[T_1,T]$.

$TC_2(T, K, \xi)$: Present worth of Total relevant cost per time unit, when $M \leq K \leq T_1$ and $T_1=\gamma T$ where $0<\gamma<1$.

$TC_1(T, \xi)$: Present worth of Total relevant cost per time unit, when $T_1 \leq M$.

Note: The total relevant cost includes following costs

(1) Cost of placing order(OC)

(2) Cost of purchasing(PC)

(3) Holding cost excluding interest charges(HC)

(4) Backordered cost (BC)

(5) Lost sales cost (LC)

(6) Interest paid for unsold times at initial time or after the permissible delay M (IP).

(7) Interest earned from sales revenue during permissible delay in payment (IE).

4.3 MATHEMATICAL MODEL FORMULATION AND SOLUTION

The inventory level gradually depleted mainly due to demand and partially due to reduced deterioration during time [0, T_1] and during [T_1, T] shortages occurs and partially backlogged. Inventory depletion during cycle length [0, T] is represented by following differential equation:

$$\frac{dI_1(t)}{dt} + \tau_p I_1(t) = -(\alpha + \beta t); \qquad 0 \le t \le T_1$$

$$\frac{dI_1(t)}{dt} + \big(\theta - m(\xi)\big) I_1(t) = -(\alpha + \beta t); \quad 0 \le t \le T_1 \tag{1}$$

and

$$\frac{dI_2(t)}{dt} = -(\alpha + \beta t)e^{-\delta t}; \qquad T_1 \le t \le T \tag{2}$$

With boundary conditions I_1 (t=0)=IM, I_1(t=T_1)=0 and I_2(t=T_1)=0.

Now solving (1), (2) and using boundary conditions, we get

$$I_1(t) = \left[\left(\alpha(T_1 - t) + \big(\beta - \alpha(\theta - m(\xi))\big)\left(\frac{T_1^2 - t^2}{2}\right) - \beta(\theta - m(\xi))\left(\frac{T_1^3 - t^3}{3}\right)\right)\big(1 - (\theta - m(\xi))t\big)\right]$$

(3)

$$I_2(t) = \left[\left(\alpha(T_1 - t) + (\beta - \alpha\delta)\left(\frac{T_1^2 - t^2}{2}\right) - \beta\delta\left(\frac{T_1^3 - t^3}{3}\right)\right)\right] \qquad (4)$$

Now the order quantity Q= IM + IB

At t=0 the inventory level is maximum. Hence

IM= I_1 (t=0) therefore from (3), we have

$$IM = \left[\left(\alpha(T_1) + \left(\beta - \alpha\left(\theta - m(\xi)\right)\right)\left(\frac{T_1^2}{2}\right) - \beta\left(\theta - m(\xi)\right)\left(\frac{T_1^3}{3}\right)\right)\right] \qquad (5)$$

The maximum backordered inventory level is

IB= -I_2 (t=T), therefore from (4), we have

$$IB = -\left[\left(\alpha(T_1 - T) + (\beta - \alpha\delta)\left(\frac{T_1^2 - T^2}{2}\right) - \beta\delta\left(\frac{T_1^3 - T^3}{3}\right)\right)\right] \qquad (6)$$

Therefore the order size Q is as follows:

$$Q = \left[\left(\alpha(T_1) + \left(\beta - \alpha\left(\theta - m(\xi)\right)\right)\left(\frac{T_1^2}{2}\right) - \beta\left(\theta - m(\xi)\right)\left(\frac{T_1^3}{3}\right)\right) - \left(\alpha(T_1 - T) + (\beta - \alpha\delta)\left(\frac{T_1^2 - T^2}{2}\right) - \beta\delta\left(\frac{T_1^3 - T^3}{3}\right)\right)\right]$$

(7)

The total relevant cost consists following cost parameters

(8)

1. The ordering cost(OC)=A
2. The Purchase Cost (PC)= C *Q

$$PC = C\left[\left(\alpha(T_1) + \left(\beta - \alpha\left(\theta - m(\xi)\right)\right)\left(\frac{T_1^2}{2}\right) - \beta\left(\theta - m(\xi)\right)\left(\frac{T_1^3}{3}\right)\right) - \left(\alpha(T_1 - T) + (\beta - \alpha\delta)\left(\frac{T_1^2 - T^2}{2}\right) - \beta\delta\left(\frac{T_1^3 - T^3}{3}\right)\right)\right]$$

(9)

3. The Present worth of Holding cost(HC)

$$HC = \int_0^{T_1} (h_1 + th_2) I_1(t)dt$$

(10)

4. Present worth of Backordered Cost (BC)

$$BC = -C_1 \int_{T_1}^{T} I_2(t)dt$$

(11)

5. Lost sales cost (LC)

$$LC = C_2 \int_{T_1}^{T} \left(1 - e^{-\delta t}\right)(\alpha + \beta t)e^{-rt}dt$$

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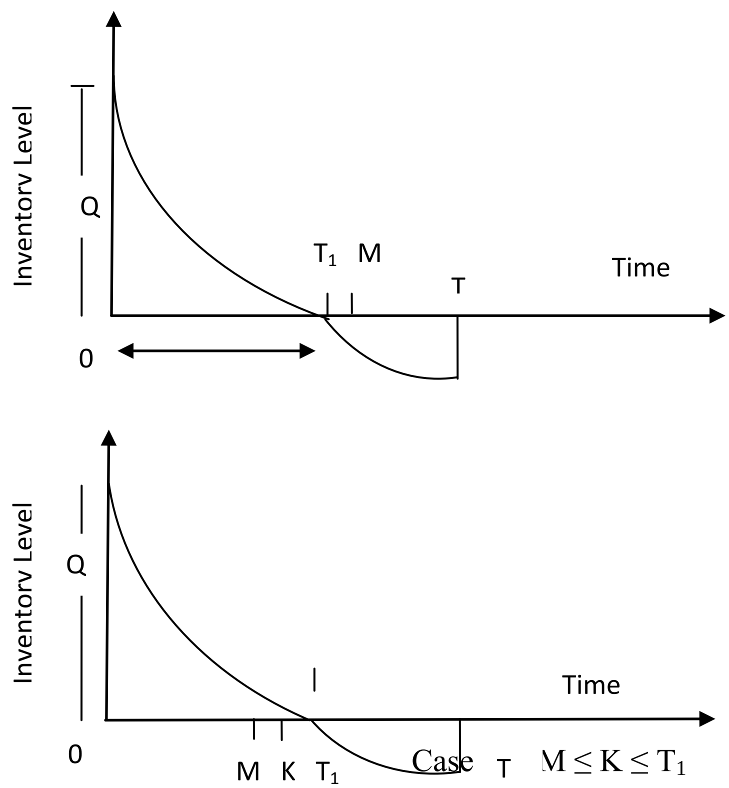
$$LC = C_2\left[\delta\left\{\alpha\left(\frac{T^2-T_1^2}{2}\right)+\beta\left(\frac{T^3-T_1^3}{3}\right)\right\}\right] \tag{12}$$

Now we will find Interest paid and earned by purchaser, for this there are two cases

(i) $T_1 < M$ (ii) $T_1 \geq M$. These two cases are graphically represented in Figure-1

Figure-1

Case (i): $T_1 < M$ (M=K)



Case 1: $T_1 < M$ (M=K)

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The permissible delay period M is greater than the total inventory depletion period i.e. T_1. Therefore there is no interest paid by purchaser to the supplier for the items. However purchaser will uses the sales revenue to earn interest at the rate of I_e during time period $[0, T_1]$ and interest from cash invested during period $[T_{1,} M]$. Therefore the total value of interest earned under effect of inflation is

$$IE_1 = I_e p[\int_0^{T_1}(\alpha + \beta t)t dt + T_1 \int_{T_1}^{M}(\alpha + \beta t)dt]\ ]$$

$$IE_1 = I_e p\left[\left\{\alpha\left(\frac{T_1^2}{2}\right) + \beta\left(\frac{T_1^3}{3}\right)\right\} + T_1\left\{\alpha(M - T_1) + \beta\left(\frac{M^2 - T_1^2}{2}\right)\right\}\right] \qquad (13)$$

Therefore total relevant cost under the effect of inflation in first case is

$$TC_1(\mathrm{T}, \mathrm{T}_1, \xi) = [OC + PC + HC + BC + LC - IE_1] \qquad (14)$$

Our objective is to minimize total cost TC_1 (T,) where $T_1=\gamma T$; $0 < \gamma < 1$. The necessary conditions for minimization are

$$\frac{\partial TC_1(T,\xi)}{\partial T} = 0\ \&\ \frac{\partial TC_1(T,\xi)}{\partial \xi} = 0$$

Solving above equations we can find optimal values, T^*, $T_1^* = \gamma T^*$ and ξ^*. The optimal value of Total relevant cost is determined provided T^*, ξ^* must satisfy the sufficient conditions

$$\frac{\partial^2 TC_1(\mathrm{T}^*,\xi^*)}{\partial T^2} > 0\ \&\ \frac{\partial^2 TC_1(\mathrm{T}^*,\xi^*)}{\partial \xi^2} > 0$$

$$\left[\left(\frac{\partial^2 TC_1(T^*,\xi^*,)}{\partial T^2}\right)\left(\frac{\partial^2 TC_1(T^*,\xi^*,)}{\partial \xi^2}\right)\right]-\left[\frac{\partial^2 TC_1(T^*,\xi^*,)}{\partial T\partial \xi}\right]^2 > 0$$

Case 2: $M \le K \le T_1$

In this case the permissible delay period M expires before the total inventory depletion period T_1; hence purchaser will have to pay interest charged on unsold items during (M, K). Therefore Present worth of interest paid by purchaser is

$$IC_2 = I_p C[\int_M^K [I_1(t)]dt$$

(15)

Now the Present worth of interest earned during positive inventory and interest from invested cost is (This expression has been used by Chang et. al.[2009])

$$IE_2 = I_e\left[p\left\{\alpha\left(\frac{T_1^2}{2}\right)+\beta\left(\frac{T_1^3}{3}\right)\right\}+(pK-CT_1)\left\{\alpha(K-T_1)+\beta\left(\frac{K^2-T_1^2}{2}\right)\right\}\right]$$

(16)

Hence the Present worth of total relevant cost is

$$C_2(T,T_1,K,\xi) =$$

T [OC + PC + HC+BC+LC + IC_2 – IE_2]

$$TC_2(T,T_1,K,\ \xi) = [A + C\left[\left(\alpha(T_1) + \left(\beta - \alpha\left(\theta - m(\xi)\right)\right)\left(\frac{T_1^2}{2}\right) -\right.\right.$$

$$\left.\left.\beta\left(\theta - m(\xi)\right)\left(\frac{T_1^3}{3}\right)\right) - \left(\alpha(T_1 - T) + (\beta - \alpha\delta)\left(\frac{T_1^2 - T^2}{2}\right) - \beta\delta\left(\frac{T_1^3 - T^3}{3}\right)\right)\right]$$

$$h_1\left[(\alpha - \theta\alpha m(\xi))\left(\frac{T_1^3}{6}\right) + (\beta - \beta\theta m(\xi))\left(\frac{T_1^4}{8}\right) - \beta\theta\left(\frac{T_1^5}{10}\right)\right]$$

$$+h_2\left[(\alpha - \theta\alpha m(\xi))\left(\frac{T_1^4}{12}\right) + (\beta - \beta\theta m(\xi))\left(\frac{T_1^5}{10}\right) - \beta\theta\left(\frac{T_1^6}{18}\right)\right]$$

$+$

$$-C_1\left[\left\{\alpha\left(T_1T - \frac{T_1^2}{2} - \frac{T^2}{2}\right) + (\beta - \alpha\delta)\left(\frac{T_1{}^2T}{2} - \frac{T_1^3}{3} - \frac{T^3}{6}\right) - \beta\delta\left(\frac{T_1{}^3T}{3} - \frac{T_1^4}{4} -\right.\right.\right.$$

$$\left.\left.\frac{T^4}{12}\right)\right\} - r\left\{\alpha\left(\frac{T_1T^2}{2} - \frac{T_1^3}{6} - \frac{T^3}{3}\right) + (\beta - \alpha\delta)\left(\frac{T_1{}^2T^2}{4} - \frac{T_1^4}{8} - \frac{T^4}{8}\right) - \beta\delta\left(\frac{T_1{}^3T^2}{6} -\right.\right.$$

$$\left.\left.\left.\frac{T_1^5}{10} - \frac{T^5}{15}\right)\right\}\right]$$

$+$

$$C_2\left[\delta\left\{\alpha\left(\frac{T^2 - T_1^2}{2}\right) + (\beta - r\alpha)\left(\frac{T^3 - T_1^3}{3}\right) - r\beta\left(\frac{T^4 - T_1^4}{4}\right)\right\}\right]$$

$+$

$$I_pC[\left(\alpha\left(T_1(K-M)-\frac{(K^2-M^2)}{2}\right)+\left(\beta-\alpha(\theta-m(\xi))\right)\left(\frac{T_1{}^2(K-M)}{2}-\frac{(K^3-M^3)}{6}\right)-\beta(\theta-m(\xi))\left(\frac{T_1^3(K-M)}{3}-\frac{(K^4-M^4)}{12}\right)\right)-$$

$$(\theta-m(\xi))\left\{\alpha\left(T_1\frac{(K^2-M^2)}{2}-\frac{(K^3-M^3)}{3}\right)+\left(\beta-\alpha(\theta-m(\xi))\right)\left(\frac{T_1{}^2(K^2-M^2)}{4}-\frac{(K^4-M^4)}{8}\right)-\beta(\theta-m(\xi))\left(\frac{T_1^3(K^2-M^2)}{6}-\frac{(K^5-M^5)}{15}\right)\right\}$$

]-

$$I_e\left[p\left\{\alpha\left(\frac{T_1^2}{2}\right)+\beta\left(\frac{T_1^3}{3}\right)\right\}+(pK-CT_1)\left\{\alpha(K-T_1)+\beta\left(\frac{K^2-T_1^2}{2}\right)\right\}\right]$$

]

(17)

To minimize total relevant cost, we differentiate TC_2 (T,K,ξ) w. r. t to $T,K \text{ and } \xi$, where $T_1=\gamma T$; $(0<\gamma<1)$ and for optimal value necessary conditions are

$$\frac{\partial TC_2(T,\xi)}{\partial T}=0,\ \frac{\partial TC_2(T,\xi)}{\partial K}=0,\frac{\partial TC_2(T,\xi)}{\partial \xi}=0$$

Provided the determinant of principal minor of hessian matrix are positive definite, i.e. det(H1)>0, det(H2)>0,det(H3)>0 where H1, H2, H3 is the principal minor 0f the Hessian-matrix.

Hessian Matrix of the total cost function is as follows:

$$\begin{bmatrix} \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial T^2} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial T \partial K} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial T \partial \xi} \\ \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial K \partial T} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial K^2} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial K \partial \xi} \\ \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial \xi \partial T} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial \xi \partial K} & \frac{\partial^2 TC_2(T^*,K^*,\xi^*)}{\partial \xi^2} \end{bmatrix}$$

4.4 **NUMERICAL ILLUSTRATION**

For the Illustration of proposed model we consider following inventory system in which values of different parameters in proper units are $A = 300, \alpha = 100, \beta = 2.5, C = 10, C_1 = 2, C_2 = 4, h_1 = 1.8, h_2 = 0.008, \theta = 0.38, \delta = 0.4, a = 5, \gamma = 0.3, I_e = 0.20, I_p = 0.4, p = 20.$ there are two cases according to the permissible delay period as follows:

Case: 1 for T < M, M= 0.3, Using mathematical software Mathematica7 the output results are as follows

T^*=0.27696, ξ^*= 0.10623, $TC_1^*(T^*, \xi^*)$ = 375.991, $Q^*(T^*, \xi^*)$ = 2.58567

Case: 2 for M≤ K ≤ T, M= 0.2, Using mathematical software Mathematica7 the output results are as follows

T^*=0.27522, K^*=0.20086, ξ^*= 0.27881, $TC_2^*(T^*, K^*, \xi^*)$ =317.945, $Q^*(T^*, K^*, \xi^*)$ =2.5786

4.6 CONCLUSION

In this model we have developed the deteriorating item with controllable deterioration rate by using preservation techniques and time dependent demand. Optimal value of total relevant cost, preservation cost, economic ordered quantity, payment time optimal cycle length are obtained by using Mathematical software Mathematica7. For sensitivity of proposed model a sensitivity analysis is performed by varying some parameters. Proposed model can be extended by considering other factors of inventory control like shortages, price dependent demand etc.

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