Yugoslav Journal of Operations Research
24 (2014) Number 1, 87-98
DOI: 10.2298/YJOR120823018M

DETERIORATING INVENTORY MODEL WITH CONTROLLABLE DETERIORATION RATE FOR TIME-DEPENDENT DEMAND AND TIME-VARYING HOLDING COST

VINOD KUMAR MISHRA

Department of Computer Science & Engineering,
B. T. Kumaon Institute of Technology,
Dwarahat, Almora, - 263653, (Uttarakhand), INDIA
vkmishra2005@gmail.com

Received: August 2012 / Accepted: April 2013

Abstract: In this paper, we develop an inventory model for non-instantaneous deteriorating items under the consideration of the facts: deterioration rate can be controlled by using the preservation technology (PT) during deteriorating period, and holding cost and demand rate both are linear function of time, which was treated as constant in most of the deteriorating inventory models. So in this paper, we developed a deterministic inventory model for non-instantaneous deteriorating items in which both demand rate and holding cost are a linear function of time, deterioration rate is constant, backlogging rate is variable and depend on the length of the next replenishment, shortages are allowed and partially backlogged. The model is solved analytically by minimizing the total cost of the inventory system. The model can be applied to optimizing the total inventory cost of non-instantaneous deteriorating items inventory for the business enterprises, where the preservation technology is used to control the deterioration rate, and demand & holding cost both are a linear function of time.

Keywords: Inventory, non-instantaneous deteriorating items, controllable deterioration rate, preservation technology, time dependent holding cost.

MSC: 90B05.

1. INTRODUCTION

Inventory System is one of the main streams of the Operations Research which is essential in business enterprises and Industries. Interest in the subject is constantly increasing, and its development in recent years closely parallels the development of operations research in general. Some authors even claim that "More operations research has been directed towards inventory control than toward any other problem area in business and industry" and among these the deteriorating items inventory have gain large emphasis in last decade. The inventory system for non-instantaneous deteriorating items has been an object of study for a long time, but little is known about the effect of investing in reducing the rate of product deterioration. So in this paper, an inventory model is developed for non-instantaneous deteriorating items by considering the fact that using the preservation technology the retailer can reduce the deterioration rate by which the retailer can reduce the economic losses, improve the customer service level and increase business competitiveness.

Donaldson [1977] gave the fundamental result in the development of economic order quantity models with time-varying demand patterns he established the classical no-shortage inventory model with a linear trend in demand over a known and finite horizon. Dave and Patel [1981] developed the deteriorating inventory model with linear trend in demand. He considered demand as a linear function of time where shortages were prohibited over the finite planning horizon. Wee and Wang [1999] developed a variable production policy for deteriorating items with time varying demand. Zhou et al. [2003] gave a new variable production scheduling strategy for deteriorating items with time-varying demand and partial lost sale. They made Wee and Wang [1999] more realistic and applicable in practice. Wu et al. [2006] and Ouyang et al. [2006] first incorporated the phenomenon of non-instantaneous deterioration. They also found that if the retailer can effectively reduce the deteriorating rate of item by improving the storage facility, the total annual relevant inventory cost will be lowered. Alamri and Balkhi [2007] gave the effects of learning and forgetting on the optimal production lot size for deteriorating items with time varying demand and deterioration rates.

In [2008] Ajanta Roy developed a deterministic inventory model when the deterioration rate is time proportional, demand rate is a function of selling price, and holding cost is time dependent. Lee and Hsu [2009] developed a production model over a finite planning horizon for deteriorating items with time-dependent demand with capacity constraint. Hsu et al [2010] developed a deteriorating inventory policy when the retailer invests on the preservation technology to reduce the rate of product deterioration. Chang et al. [2010] gave optimal replenishment policy for non instantaneous deteriorating items with stock dependent demand. Dye and Ouyang [2011] studied a deteriorating inventory system with fluctuating demand and trade credit financing, and established a deterministic economic order quantity model for a retailer to determine its optimal selling price, replenishment number and replenishment schedule with fluctuating demand under two levels of trade credit policy. Hung [2011] gave an inventory model with generalized type demand, deterioration and backorder rates. Mishra V. and Singh L. [2011] developed deteriorating inventory model for time dependent demand and holding cost with partial backlogging. Leea and Dye [2012] formulated a deteriorating inventory model with stock-dependent demand by allowing preservation technology cost as a decision variable in conjunction with replacement policy. Maihami and Kamalabadi

[2012] developed a joint pricing and inventory control system for non-instantaneous deteriorating items, and adopt a price and time dependent demand function. Sarkar [2012] investigated an EOQ model with delay-in-payments and time-varying deterioration rate. Dye and Hsieh [2012] presented an extended model of Hsu et al. [2010] by assuming that the preservation technology cost is a function of the length of replenishment cycle. Shah et al. [2013] integrated time varying deterioration and holding cost rates in the inventory model where shortages were not prohibited. The main objective in their model is to find the retailer's replenishment, selling price and advertisement strategies which maximize the retailer's unit time profit. Mishra et al. (2013) gave an inventory model for deteriorating items with time-dependent demand and time-varying holding cost under partial backlogging.

The deterioration rate of inventory items in the above mentioned papers is viewed as an exogenous variable, which is not subject to control. In practice, the deterioration rate of products can be controlled and reduced through various efforts such as procedural changes and specialized equipment acquisition. The consideration of PT is important due to rapid social changes, and the fact that PT can reduce the deterioration rate significantly. By the efforts of investing in preservation technology, we can reduce the deterioration rate. So in this paper, we made the model of Mishra and Singh [2011] more realistic by considering the fact that the use preservation technology can reduce the deterioration rate significantly, which help the retailers to reduce their economic losses.

The assumptions and notations of the model are introduced in the next section. The mathematical model is derived in section 3, solution procedure & algorithm are derived in section 4, and numerical illustration is presented in section 5. The article ends with some concluding remarks and scope of a future research

2. ASSUMPTIONS AND NOTATIONS

The mathematical model is based on the following notations and assumptions.

2.1 Notations

- A the ordering cost per order.
- C the purchase cost per unit.
- $h(t)$ the inventory holding cost per unit per time unit.
- π_b the backordered cost per unit short per time unit.
- π_l the cost of lost sales per unit.
- ξ preservation technology (PT) cost for reducing deterioration rate in order to preserve the product, $\xi > 0$.
- θ the deterioration rate.
- $m(\xi)$ reduced deterioration rate due to use of preservation technology.
- τ_p resultant deterioration rate, $\tau_p = (\theta - m(\xi))$.
- t_d the time from which the deterioration start in the inventory.
- t_1 the time at which the inventory level reaches zero, $t_1 \geq 0$.
- t_2 the length of period during which shortages are allowed, $t_2 \geq 0$.

- $T(=t_1+t_2)$ the length of cycle time.
- IM the maximum inventory level during [0, T].
- IB the maximum inventory level during shortage period.
- $Q(=IM+IB)$ the order quantity during a cycle of length T.
- $I1(t)$ the level of positive inventory at time t, $0 \le t \le t_d$,
- $I2(t)$ the level of positive inventory at time t, $t_d \le t \le t_1$.
- $I2(t)$ the level of negative inventory at time t, $t_1 \le t \le t_1 + t_2$.
- $TC(t_1, t_2, \xi)$ the total cost per time unit.

2.2 Assumptions

- The demand rate is time dependent that is if ‘a’ is fix fraction of demand and ‘b’ is that fraction of demand which is vary with time then demand function is f(t) = a + b t, where a>0 ,b>0.
- Preservation technology is used for controlling the deterioration rate.
- Holding cost is linear function of time h(t)= α + βt ,α ≥ 0,β ≥ 0.
- Shortages are allowed and partially backlogged.
- The lead time is zero.
- The replenishment rate is infinite.
- The planning horizon is finite.
- The deterioration rate is constant.
- During stock out period, the backlogging rate is variable and is dependent on the length of the waiting time for next replenishment. So that the backlogging rate for negative inventory is, $B(t) = \frac{1}{1+\delta(T-t)}$ δ is backlogging parameter and (T-t) is waiting time $(t_1 \le t \le T)$.

3. MATHEMATICAL MODEL

The rate of change of inventory during positive stock period [0,t_1] and shortage period [t_1,T] is governed by the differential equations

$$\frac{dI_1(t)}{dt} = -(a+bt); \quad 0 \le t \le t_d \tag{1}$$

$$\frac{dI_2(t)}{dt} + \tau_p I_1(t) = -(a+bt); \quad t_d \le t \le t_1 \tag{2}$$

$$\frac{dI_3(t)}{dt} = \frac{-(a+bt)}{1+\delta(T-1)}; \quad t_1 \le t \le T \tag{3}$$

With boundary condition

$I_2(t) = I_3(t) = 0$ at $t = t_1, I_1(t) = I_2(t)$ at $t = t_d$ and $I_1(t) = IM$ at $t = 0$

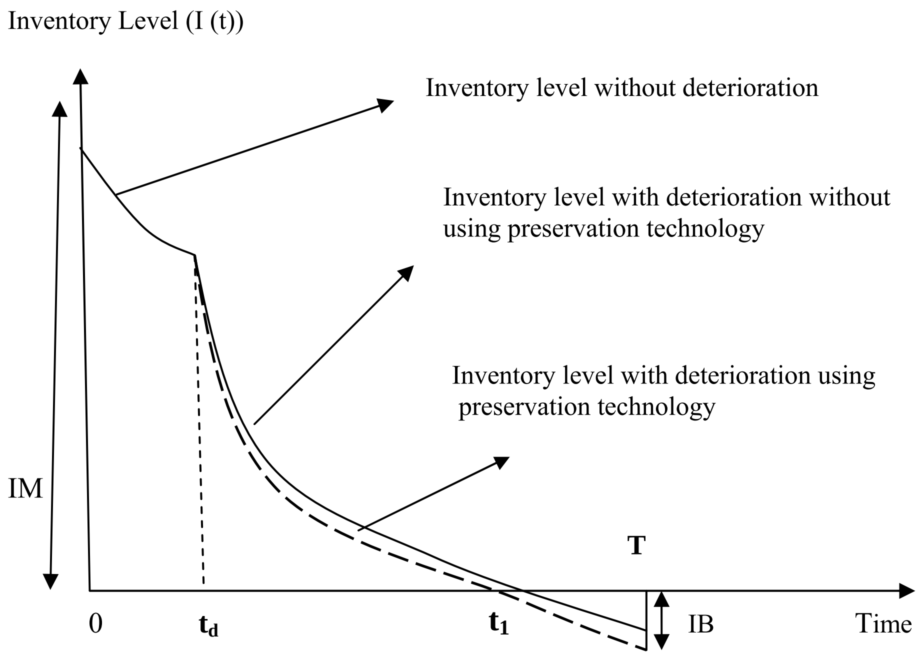

Figure 1: Graphical Representation of Inventory System

4. ANALYTICAL SOLUTION

Case I: Inventory level without shortage

During the positive stock period [0, t_1], the inventory depletes during [0, t_d] due to demand and during [t_d, t_1] due to resultant deterioration and demand both. Hence, the inventory level at any time during [0, t_1] is described by differential equations

$$\frac{dI_1(t)}{dt} = -(a+bt); \quad 0 \le t \le t_d \tag{4}$$

$$\frac{dI_2(t)}{dt} + \tau_p I_1(t) = -(a+bt); \quad t_d \le t \le t_1 \tag{5}$$

With the boundary condition $I_2(t) = 0$ at $t = t_1$, $I_1(t) = I_2(t)$ at $t = t_d$ and $I_1(t) = IM$ at $t = 0$.

The solution of equation (4) and (5) are as follows

$$I_1(t)=\begin{bmatrix} a(t_d-t)+\frac{b(t_d^2-t^2)}{2}+\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_d\,\frac{1}{\theta-m(\xi)})- \\ e^{(\theta-m(\xi))(t_1-t_d)}\left[\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_1-\frac{1}{\theta-m(\xi)})\right] \end{bmatrix}, 0\le t\le t_d \quad (6)$$

$$I_2(t)=\begin{bmatrix} -\frac{a}{\theta-m(\xi)}-\frac{b}{\theta-m(\xi)}(t_d\,\frac{1}{\theta-m(\xi)})+ \\ e^{(\theta-m(\xi))(t_1-t)}\left[\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_1-\frac{1}{\theta-m(\xi)})\right] \end{bmatrix}, t_d\le t\le t_1 \quad (7)$$

Case II: Inventory level with shortage

During the interval $[t_1, T]$ the inventory level depends on demand and a fraction of demand is backlogged. The state of inventory during $[t_1, T]$ can be represented by the differential equation

$$\frac{dI_3(t)}{dt}=\frac{-(a+bt)}{1+\delta(t_1+t_2-t)};\quad t_1\le t\le t_1+t_2 \quad (8)$$

With the boundary condition $I_2(t_1)=0$ at $t=t_1$

The Solution of equation (8) is

$$I_3(t)=\begin{bmatrix} \frac{a}{\delta}\log\frac{1+\delta(t_1+t_2-t)}{1+\delta t_2}+\frac{b\left[1+\delta(t_1+t_2)\right]}{\delta^2}\log\frac{\left[1+\delta(t_1+t_2-t)\right]}{1+\delta t_2} \\ -\frac{b(t_1-t)}{\delta} \end{bmatrix} \quad (9)$$

Therefore the total cost per replenishment cycle consists of the following components:

1) Inventory holding cost per cycle;

$$IHC = \int_0^{t_1} h(t)[I_1(t) + I_2(t)]dt$$

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

$$IHC = \left[\begin{array}{l} \alpha\left(\frac{at_d^2}{2} + \frac{bt_d^3}{3}\right) + \beta\left(\frac{at_d^3}{6} + \frac{bt_d^4}{8}\right) + t_d \left[\begin{array}{l} \frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_d - \frac{1}{\theta - m(\xi)}) - \\ e^{(\theta - m(\xi))(t_1 - t_d)}\left(\begin{array}{l} \frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)} \\ (t_1 - \frac{1}{\theta - m(\xi)}) \end{array}\right) \end{array}\right] \\ -\frac{1}{6(\theta - m(\xi))^4}\left[\begin{array}{l} \left(-6\beta b - 6(\theta - m(\xi))(b\alpha - a\beta)\right) + 6(\theta - m(\xi))^2(a\beta t_1 + b\alpha t_d) \\ +3b\beta(\theta - m(\xi))^2(t_d^2 - t_1^2) + 6a\alpha(\theta - m(\xi))^2 + 2b\beta(\theta - m(\xi))^3 \\ (t_1^3 - t_d^3) + 3a\beta(\theta - m(\xi))^3(t_1^2 - t_d^2) + 3b\alpha(\theta - m(\xi))^3(t_1^2 - t_d^2) \\ +6a\alpha(\theta - m(\xi))^3(t_1 - t_d) + 6e^{(\theta - m(\xi))(t_1 - t_d)} \\ \left(\begin{array}{l} 6(\theta - m(\xi))(b\alpha - a\beta) - 6b\beta(\theta - m(\xi))(t_1 - t_d) \\ -6(\theta - m(\xi))^2(a\alpha + b\beta t_1 t_d + a\beta t_d + b\alpha t_1) + b\beta \end{array}\right) \end{array}\right] \end{array}\right] \quad (10)$$

2) Backordered cost per cycle;

$$BC = \pi_b\left(\int_{t_1}^{t_1+t_2} -I_3(t)dt\right)$$

$$BC = \pi_b \left(\begin{array}{l} (\frac{1}{2\delta^3}(2at_2\delta^2 + bt_2^2\delta^2 + 2bt_1t_2\delta^2 + 2b\delta t_2 + 2bt_2\delta\log(\frac{1}{1+\delta t_2}) \\ +2b\log(\frac{1}{1+\delta t_2}) + 2a\delta\log(\frac{1}{1+\delta t_2}) + 2bt_1\delta\log(\frac{1}{1+\delta t_2}))) \end{array}\right) \quad (11)$$

3) Lost sales cost per cycle;

$$LS = \pi_l\left(\int_{t_1}^{t_1 t_2}\left(1 - \frac{1}{1+\delta(t_1 + t_2 - t)}(a + bt)\right)dt\right)$$

$$LS = \pi_l \left(\begin{array}{l} (\frac{1}{2\delta^2}(2at2\delta 2 + 2bt1t2\delta 2 + bt_2^2\delta 2 - 2b\delta\log(1 + \delta t_2) \\ -2b\log(1+\delta t_2) - 2b\delta t1\log(1+\delta t_2) - 2b\delta t2\log(1+\delta t_2) + 2b\delta t2)) \end{array}\right) \quad (12)$$

4) Purchase cost per cycle = (purchase cost per unit) * (Order quantity in one cycle)

$$PC = C * Q$$

When t = 0 the level of inventory is maximum and it is denoted by IM (= I_1 (0)) then from the equation (6)

$$IM = \begin{bmatrix} at_d + \frac{bt_d^2}{2} + \frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_d - \frac{1}{\theta - m(\xi)}) - \\ e^{(\theta - m(\xi))(t_1 - t_d)}\left[\frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_1 - \frac{1}{\theta - m(\xi)})\right] \end{bmatrix} \tag{13}$$

The maximum backordered inventory is obtained at t = t_1 +t_2 then from the equation (6)

$$IB = -I_3(t_1 + t_2)$$

$$IB = -\left[\frac{a}{\delta}\log\frac{1}{1+\delta t_2} + \frac{b[1+\delta(t_1+t_2)]}{\delta^2}\log\frac{1}{1+\delta t_2} + \frac{bt_2}{\delta}\right] \tag{14}$$

Thus the order size during total time interval [0,T]

$$Q = IM + IB$$

Now from equations (13) and (14)

$$Q = \begin{bmatrix} at_d + \frac{bt_d^2}{2} + \frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_d - \frac{1}{\theta - m(\xi)}) - \\ e^{(\theta - m(\xi))(t_1 - t_d)}\left[\frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_1 - \frac{1}{\theta - m(\xi)})\right] \\ -\frac{a}{\delta}\log\frac{1}{1+\delta t_2} - \frac{b[1+\delta(t_1+t_2)]}{\delta^2}\log(1+\delta t_2) - \frac{bt2}{\delta} \end{bmatrix} \tag{15}$$

Thus

$$PC = C * Q$$

$$C = \begin{bmatrix} at_d + \frac{bt_d^2}{2} + \frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_d - \frac{1}{\theta - m(\xi)}) - \\ e^{(\theta - m(\xi))(t_1 - t_d)}\left[\frac{a}{\theta - m(\xi)} + \frac{b}{\theta - m(\xi)}(t_1 - \frac{1}{\theta - m(\xi)})\right] \\ -\frac{a}{\delta}\log\frac{1}{1+\delta t_2} - \frac{b[1+\delta(t_1+t_2)]}{\delta^2}\log(1+\delta t_2) - \frac{bt2}{\delta} \end{bmatrix} \tag{16}$$

5) Ordering Cost

$$OC = A \tag{17}$$

Therefore the total cost per time unit is given by,

$=\frac{1}{(t_1+t_2)}$ [Ordering cost + carrying cost + backordering cost + lost sale cost + purchase Cost]

$$TC(t_1,t_2,\xi)=\frac{1}{(t_1+t_2)}\left[OC+IHC+BC+LS+PC\right]$$

Putting the values of OC, IHC, BC, LS and PC then,

$$TC(t_1,t)=$$

$$\frac{1}{(t_1+t_2)}\left[\begin{array}{l}
A+\alpha(\frac{at_d^2}{2}+\frac{at_d^3}{3})+\beta(\frac{at_d^3}{6}+\frac{at_d^4}{8})+t_d\left[\begin{array}{l}\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_d-\frac{1}{\theta-m(\xi)})-\\ e^{(\theta-m(\xi))(t_1-t_d)}\left(\begin{array}{l}\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}\\ t_1-\frac{1}{\theta-m(\xi)}\end{array}\right)\end{array}\right]\\
-\frac{a}{6(\theta-m(\xi))^4}\left[\begin{array}{l}(-6\beta b-6(\theta-m(\xi))(b\alpha-a\beta)+6(\theta-m(\xi))^2(a\beta t_1+b\alpha t_d)\\ +3b\beta(\theta-m(\xi))^2(t_d^2-t_1^2)+6a\alpha(\theta-m(\xi))^2+2b\beta\theta-m(\xi)^3(t_1^3-t_d^3)\\ +3a\beta(\theta-m(\xi))^3(t_1^2-t_d^2)+3b\alpha(\theta-m(\xi))^3(t_1^2-t_d^2)\\ +6a\alpha(\theta-m(\xi)^3(t_1-t_d)\\ +6e^{(\theta-m(\xi))(t_1-t_d)}\left(\begin{array}{l}6(\theta-m(\xi))(b\alpha-a\beta)-6b\alpha(\theta-m(\xi)(t_1-t_d)\\ -6(\theta-m(\xi))^2(a\alpha-b\beta t_1-t_d+a\beta t_d+b\alpha t_1)+b\beta\end{array}\right)\end{array}\right]\\
+\frac{1}{2\delta^2}(\pi_1(2at_2\delta^2+2bt_1t_2\delta^2+bt_2\delta-2a\delta\log(1+\delta t_2)-2b\log(1+\delta t_2)-2bt_1\delta\log(1+\delta t_2)\\
-2bt_2\delta\log(1+\delta t_2)+2b\delta t_2))+\frac{1}{2\delta^3}(\pi_b(2at_2\delta^2+bt_2^2\delta^2+2bt_1t_2\delta^2+2a\delta t_2+\\
2bt_2\log(\frac{1}{1+\delta t_2})\delta+2b\log(\frac{1}{1+\delta t_2})+2a\log(\frac{1}{1+\delta t_2})\delta+2b\log(\frac{1}{1+\delta t_2})t_1\delta))\\
+c\left(\left[\begin{array}{l}at_d+\frac{bt_d^3}{2}+\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_d-\frac{1}{\theta-m(\xi)})-\\ e^{(\theta-m(\xi))(t_1-t_d)}\left[\frac{a}{\theta-m(\xi)}+\frac{b}{\theta-m(\xi)}(t_1\frac{b}{\theta-m(\xi)})\right]\\ -\frac{a}{\delta}\log\frac{1}{1+\delta t_2}-\frac{b\left[1+\delta(t_1+t_2)\right]}{\delta^2}\log(1+\delta t_2)-\frac{bt2}{\delta}\end{array}\right]\right)
\end{array}\right] \quad (18)$$

Differentiates the equations (18) with respect to t_1, t_2 and ξ then we get

$$\frac{\partial TC}{\partial t_1},\frac{\partial TC}{\partial t_2}\,and\,\frac{\partial TC}{\partial \xi}$$

To minimize the total cost $TC(t_1,t_2,\xi)$ per unit time the optimal value of t_1, t_2 and ξ can be obtained by solving the following equations

$$\frac{\partial TC}{\partial t_1}=0\frac{\partial TC}{\partial t_2} and \frac{\partial TC}{\partial \xi}=0 \qquad (19)$$

Provided the determinant of principal minor of hessian matrix (H-matrix) of $TC(t_1,t_2,\xi)$ is positive definite. i.e. det(H_1)>0, det(H_2)>0,det(H_3)>0 where H_1, H_2, H_3 is the principal minor of the H-matrix.

The H-matrix of function $TC(t_1,t_2,\xi)$ is defined as

$$H=\begin{bmatrix} \frac{\partial^2 TC}{\partial t_1^2} & \frac{\partial^2 TC}{\partial t_1 \partial t_2} & \frac{\partial^2 TC}{\partial t_1 \partial_{\xi}} \\ \frac{\partial^2 TC}{\partial t_1 \partial t_2} & \frac{\partial^2 TC}{\partial t_2^2} & \frac{\partial^2 TC}{\partial t_2 \partial_{\xi}} \\ \frac{\partial^2 TC}{\partial \xi t_1} & \frac{\partial^2 TC}{\partial \xi t_2} & \frac{\partial^2 TC}{\partial \xi^2} \end{bmatrix}$$

Algorithm for solution of the model

Step-1: Start
Step-2: Initialize the value of the variable A, α, β, C,t_d π_b, π_l, δ, a, b, θ and m (ξ).
Step-3: Evaluate $TC(t_1,t_2,\xi)$
Step-4: Evaluate $\frac{\partial TC}{\partial t_1},\frac{\partial TC}{\partial t_2} and \frac{\partial TC}{\partial \xi}$
Step-5: Solve the simultaneous equation $\frac{\partial TC}{\partial t_1}=0\frac{\partial TC}{\partial t_2} and \frac{\partial TC}{\partial \xi}=0$
Step-6: Choose one set of solution from step-5.
Step-7: Evaluate PM1= det(H_1), PM2=det(H_2) andPM3= det(H_3).(where H_1, H_2, H_3 is the principal minor of the H-matrix.
Step-8: If the value of PM1, PM2 and PM3 is greater than zero then this set of solution is optimal & go to step 10.
Step-9: otherwise go to step-5
Step-10: End

5. NUMERICAL ILLUSTRATION

For numerical illustration we consider an inventory system with the following parameter in proper unit A=2500, α=4, β=0.02, C=5, π_b=10, π_l=8, δ=5, t_d=0.5,a=20, b=25, θ=0.5 and m (ξ) =θ (1-e^{-05k}). The computer output of the program by using maple mathematical software is t1 = 0.66, t2 = 3.94 and ξ= 2.29. i.e. the value of t1 at which the inventory level become zero is 0.66 unit time , shortage period is 3.94 unit time and the optimal value of preservation technology cost is 2.29 per unit & total cost is 1266.63.

6. CONCLUSION

The purpose of this study is to present an inventory model for non-instantaneous deteriorating items involving controllable deterioration rate to extend the traditional EOQ model. The products with high deterioration rate are always crucible to the retailer's business. In real markets, the retailer can reduce the deterioration rate of a product by making effective capital investment in storehouse equipment. In this study, to reduce the deterioration rate during deterioration period of non-instantaneous deteriorating items inventory, we use the preservation technology, and a solution procedure to determine an optimal replenishment cycle, shortage period, order quantity and preservation technology cost so that the total inventory cost per unit time is minimum. A numerical example has been presented to illustrate the model. This non-instantaneous deteriorating inventory model is very practical for the retailers who use the preservation technology in their warehouses to control the deterioration rate under assumptions different from those in this model. The numerical analysis of the model shows that the solution of the model is quite stable. This model can further be extended by taking more realistic assumptions such as finite replenishment rate, Probabilistic demand rate etc.

REFERENCES

[1] Alamri, A.A., Balkhi, Z.T., "The effects of learning and forgetting on the optimal production lot size for deteriorating items with time varying demand and deterioration rates", *International Journal of Production Economics*, 107 (2007) 125-138.

[2] Chang, C.T. ,Teng J.T. & Goyal, S. K., "Optimal Replenishment policies for non instantaneous deteriorating items", *International Journal of Production Economics*, 123(1) (2010) 62-68.

[3] Dave, U. and Patel, L.K., "(T, Si) - policy inventory model for deteriorating items with time proportional demand", *Journal of Operational Research Society*, 32 (1981) 137-142.

[4] Donaldson,W.A., "Inventory replenishment policy for a linear trend in demand—an analytical solution", *Operational Research Quarterly*, 28 (3) (1977) 663–670.

[5] Dye, C.Y., & Hsieh, T.P., "An optimal replenishment policy for deteriorating items with effective investment in preservation technology", *European Journal of Operational Research*, 218(1) (2012) 106–112.

[6] Dye, C.-Y. & Ouyang,L.-Y., "A particle swarm optimization for solving joint pricing and lot-sizing problem with fluctuating demand and trade credit financing", *Computers & Industrial Engineering*, 60(1) (2011) 127–137.

[7] Hsu, P.H., Wee, H.M., and H.M., Teng, "Preservation technology investment for deteriorating inventory", *International Journal of Production Economics*, 124(2) (2010) 388–394.

[8] Hung, K.-C., "An inventory model with generalized type demand, deterioration and backorder rates", *European Journal of Operational Research*, 208(3) (2011) 239-242.

[9] Lee,C.C., & Hsu, S.-L., "A two-warehouse production model for deteriorating inventory items with time-dependent demands", *European Journal of Operational Research*, 194 (3) (2009) 700–710.

[10] Leea,Y.-P., & Dye, C.-Y., "An inventory model for deteriorating items under stock-dependent demand and controllable deterioration rate", *Computers & Industrial Engineering*, 63(2) (2012) 474–482.

[11] Maihami, R., and Kamalabadi, I.N., "Joint pricing and inventory control for non-instantaneousdeteriorating items with partial backlogging and time and price dependent demand", *International Journal of Production Economics*, 136(1) (2012) 116–122.

[12] Mishra, V.K., and Singh, L.S., "Deteriorating inventory model for time dependent demand and holding cost with partial backlogging", *International Journal of Management Science and Engineering Management*, 6(4) (2011) 267-271.
[13] Mishra, V.K., Singh, L.S., & Kumar, R., "An inventory model for deteriorating items with time-dependent demand and time-varying holding cost under partial backlogging", *Journal of Industrial Engineering International* 9:4 (2013).
[14] Ouyang, L.Y., Wu, K.S., &Yang, C.T., "A study on an inventory model for non-instantaneous deteriorating items with permissible delay in payments", *Computers & Industrial Engineering,* 51(4) (2006) 637–651.
[15] Roy, Ajanta, "An inventory model for deteriorating items with price dependent demand and time varying holding cost", *Advanced Modeling and Optimization*, 10 (2008) 25-37
[16] Sarkar, B., "An EOQ model with delay-in-payments and time-varying deterioration rate", *Mathematical and Computer Modelling*, 55 (2012) 367–377.
[17] Shah, N.H., Soni, H.N., & Patel, K.A., "Optimizing inventory and marketing policy for non-instantaneous deteriorating items with generalized type deterioration and holding cost rates", *Omega*, 41(2) (2013) 421–430.
[18] Wee, H.-M., & Wang,W.-T., "A variable production scheduling policy for deteriorating items with time-varying demand", *Computers & Operations Research*, 26 (3) (1999) 237–254.
[19] Wu, K.S., Ouyang, L.Y., & Yang, C.T., "An optimal replenishment policy for non-instantaneous deteriorating items with stock-dependent demand and partial backlogging", *International Journal of Production Economics*, 101(2) (2006) 369–384.
[20] Zhou, Y.-W., Lau, H.-S. & Yang, S.-L., Yang, "A new variable production scheduling strategy for deteriorating items with time-varying demand and partial lost sale", *Computers & Operations Research*, 30 (12) (2003)1753–1776.