Global Journal of Pure and Applied Mathematics.
ISSN 0973-1768 Volume 13, Number 9 (2017), pp. 5977-5995

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A Cost Minimization Inventory Model for Deteriorating Products and Partial Backlogging under Inflationary Environment

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Abstract

In this paper an inventory model for deteriorating products under inflationary environment has been developed. The model is developed for finite time horizon. Inflation plays a very significant role in the development of an inventory model, since the different associated costs changes with time. So to develop the inventory models without considering the effect of inflation will mislead the results. It should be treated as a permanent parameter in the development of inventory models. Shortages are allowed and assumed to be partially backlogged in this model. Numerical example and sensitivity analysis are also cited to illustrate this study.

Keywords: Inventory, Deterioration, Inflation, Shortages, Partial backlogging.

I. INTRODUCTION

In real life, there are several items such as medicines, edible products, fruits, vegetables, electronic products, blood bank and many more in our surroundings, which deteriorate continuously due to obsolescence, spoilage, evaporation, weather etc. But in literature, rate of deterioration is assumed as a variable that cannot be controlled while in realistic situation deteriorating nature of any product can be controlled up to highest extent. It is possible with the help of preservation techniques. It can be done through technical changes or through a specialized equipment acquisition. Due to social and environment changes, preservation techniques becomes very important for deteriorating inventory systems .In literature review, the effect of preservation techniques has been observed by Lee and Dye (2012). Mishra (2013) is another who has incorporated the concept of preservation technology investment for deteriorating inventory.

The continuous degradation in quality of a product is known as deterioration. The concept of deterioration was first introduced by Ghare and Schrader (1963). They have studied the constant rate of deterioration. Further many researchers like Shah and Jaiswal (1977), Padmanabhana and Vratb (1995), and Yang and Wee (2000) etc. have focused on deteriorating inventory.

Demand rate plays a crucial role in study of deteriorating inventory. Resh, Friedman, Barbosa (1976) are the first who have incorporated the concept of linear trends in demand. Considering time-proportional demand an EOQ model for deteriorating items was developed by Dave and Patel (1981). The basic result in the development of EOQ models with time-varying demand patterns was given by Donaldson (1977) and he established the classical no shortage inventory model with a linear trend in demand over a known and finite horizon. Bose et.al (1995) developed an EOQ model for deteriorating product with linear time dependent demand rate and shortage under inflation and time discounting. Bracer at al. (1988) discussed a deterministic inventory level- dependent demand rate. The concept of constant demand rate has been studied by Chung and Lin (2001), Jaggi and verma (2010), Singh and Singh (2010) etc.

Due to excess demand, stock level approaches to zero. In order to avoid this situation, suppliers try to hold their customers and for this they have considered the partially backlogged shortages. Several researchers have been discussed about the shortage conditions like Ghosh S.K. and Chaudhuri K.S. (2005), Hou K.L.(2006) ,Singh and Singh (2007), Singh, Kumari, Kumar (2010), Ghiami, Williams , Wu (2013) , Taleizadch et.al. (2013), etc.

It has been observed that so many countries, after 1970’s, are suffered by the inflation and time value of money. Buzacot (1975) first of all discussed the effect of inflation in his work and after that several researchers have implemented it in their work in different ways. Cherna at el. (2008) presented a partial backlogging inventory lot-size models for the perishable products with variable demand under inflation. Jaggi C.K., Aggarwal K.K. and Goel S.K. (2007) developed an optimal ordering policy for the perishable product with inflation induced demand. We can find other exciting thoughts in Chang C.T.(2004), Chern M.S.,Yang H.L.,Teng J.T. and Papachristos

S.(2008),Dye, Mandal, Maiti (2008), Sarkar, Sana, Chaudhuri (2010, 2011), Patra and Ratha (2012) etc.

In order to attract more customers, supplier provides a period to settle the account (Trade Credit). After this period an interest is charged on the products that are unsold within a specified span of time. For the similar research work, one can go for literature review of researchers like Teng, Chang, Goyal (2005), Huang Y.F.(2007), Huang Y.-F. and Huang H.-F.(2008), Kumar, Tripathy, Singh (2008), Chang, Wu, Chen (2009), Chen and Kang (2010), Chen and Cheng (2011), Jaggi, Goel, Mittal (2011), Singh, Kumari, Kumar (2011) and Yadav, Singh, Kumari (2013) , Khanra S., Mandal B., and Sarkar B.(2013), Kumar Vipin. ,Pathak Gopal. and Gupta C.B.(2013).

In this paper, an inventory model for deteriorating products under inflationary environment has been developed for finite time horizon. Inflation plays a very significant role in the development of an inventory model, so to develop the inventory models without considering the effect of inflation will mislead the results. Therefore, it should be treated as a permanent parameter in the development of inventory models. We have formulated a mathematical model for deteriorating inventory with partially backlogged shortages and demand as well as holding cost which are treated as linear function of time. Further we have studied the effect of preservation technology on deterioration rate under the effect of inflation and trade credit. We have divided this paper in eight different sections. In the second, assumptions and notation are given for mathematical model formulations which are elaborated in the third section. Cost analysis and solution procedure are given in fourth and fifth section respectively. Numerical illustration is mentioned in sixth sections and sensitivity analysis is mentioned in seventh sections of this paper. In the eighth section, we have concluded our model.

II. ASSUMPTIONS AND NOTATIONS

We consider the following assumptions:

(a) The time horizon is infinite.

(b) Lead time is negligible.

(c) Replacement rate is infinite.

(d) The Deterioration rate $\theta(t) = \alpha\beta t^{(\beta-1)}$ $(\alpha \succ 0, \beta \succ 0, t \succ 0)$. There is no replacement or repair of deteriorated units during the period.

(e) Demand rate $D(t) = a$ is constant

(f) Shortages are backlogged at the rate λ

We consider the following notations

H	:	Complete planning horizon, which has been divided into N equal parts.
$I_1(t)$	:	Inventory level during time period $(0 \le t \le v)$.
$I_2(t)$	:	Inventory level during time period $(v \le t \le T)$.
I_0	:	Initial Inventory level.
v	:	The time where shortages occur.
c	:	Purchasing cost per unit.
A	:	Ordering cost.
h	:	Holding cost per unit.
s	:	Shortage cost per unit.
l	:	Lost sale cost per unit.
$T.C.$	:	Total cost of the system.
r	:	Inflation rate

III. MATHEMATICAL FORMULATION

The complete planning horizon H has been divided into N equal parts. Thus the each cycle will be the length of H/N. In each replenishment cycle the initial inventory level is denoted by I_0. During [0, v] the inventory level decreases due to demand and deterioration and after t = v shortages occurs. At the end of replenishment cycle the shortage level is maximum. The next order is placed such that it can satisfy the backlogged demand and again piles the initial inventory level. The below mentioned figure (1) shows the pictorial representation of this system. The differential equations showing the behavior of the system are as follows:

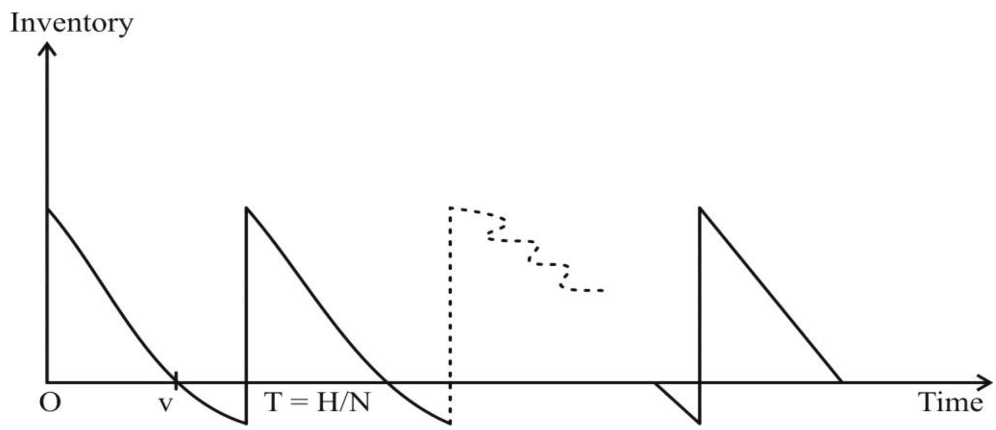

Fig.1: Graphical representation of inventory system

$$\frac{dI_1(t)}{dt}+\theta(t)I_1(t)=-D(t) \qquad 0\le t\le v \qquad \ldots(1)$$

$$\frac{dI_2(t)}{dt}=-D(t) \qquad v\le t\le T \qquad \ldots(2)$$

With boundary condition

$$I_1\left(v\right)=0, \quad I_2\left(v\right)=0$$

$$\frac{dI_1(t)}{dt}+\alpha\beta t^{\beta-1}I_1(t)=-a \qquad 0\le t\le v \qquad \ldots(3)$$

$$\frac{dI_2(t)}{dt}=-a \qquad v\le t\le T \qquad \ldots(4)$$

With boundary condition

$$I_1(v)=0, \quad I_2(v)=0$$

The solutions of these equations are given as follows:

$$I_1(t)=a\left\lfloor\left(v-t\right)+\frac{\alpha}{\left(\beta+1\right)}\left(v^{(\beta+1)}-t^{(\beta+1)}\right)-\alpha\left(v-t\right)t^{\beta}\right\rfloor \quad 0\le t\le v \qquad \ldots(5)$$

Neglect higher power of α , we get

$$I_2(t)=a(v-t) \qquad v\le t\le T \qquad \ldots(6)$$

With the help of equation (4) we can find the initial inventory level I_0 as:

$$I_0=a\left(v+\frac{\alpha}{(\beta+1)}v^{(\beta+1)}\right) \qquad \ldots(7)$$

Equation (7) shows that the initial inventory level I_0 is the function of time *v* only.

In this model the purpose of our study is to minimize the present value of total cost of the system.

IV. COST ANALYSIS

(1) Present worth of Purchasing Cost: The initial inventory stock is purchased at the beginning of each replenishment cycle so there will be no inflation at this purchasing cost, but the backlogged amount during stock out is purchased at the end of the cycle, so the present value of purchasing cost is:

$$P.C. = cI_0 + ce^{-rT}\int_v^T \lambda a\, dt$$

$$P.C. = ca\left[\left(v + \frac{\alpha}{(\beta+1)}v^{\beta+1}\right) + \lambda(T-v)e^{-rT}\right] \qquad \dots(8)$$

(2) Present Worth of Ordering Cost: The order is placed at the beginning of each replenishment cycle, so the present value of ordering cost for all the cycles will be:

$$O.C. = A \qquad \dots(9)$$

(3) Present Worth of Holding Cost: The Inventory is stocked in the warehouse for the duration of [0, v]. So the present value of inventory holding cost will be:

$$H.C. = h\int_0^v I_1(t)e^{-rt}dt$$

$$H.C. = ha\left[\frac{v^2}{2} + \frac{\alpha\beta}{(\beta+1)(\beta+2)}v^{(\beta+2)} - \frac{r}{6}v^3 + \frac{\alpha\beta r}{2(\beta+2)(\beta+3)}v^{(\beta+3)}\right] \qquad \dots(10)$$

(4) Present Worth of Shortage Cost: The shortages occur during the time interval [v, T]. The present value of shortage cost will be as follow:

$$S.C. = s\int_v^T -I_2(t)e^{-rt}dt$$

$$S.C. = s\int_v^T -a(v-t)e^{-rt}\, dt$$

$$S.C. = sa\left[\frac{e^{-rv}}{r^2} - \frac{e^{-rT}}{r^2} - \frac{(T-v)e^{-rT}}{r}\right] \qquad \dots(11)$$

(5) Present Worth of Lost Sale Cost: During stock out, only a certain ratio of customers come back to complete their demand and rest of the demand become as a lost sale. So the present value of lost sale cost will be:

$$L.S.C. = l\int_{v}^{T} a(1-\lambda)e^{-rT}dt$$

$$L.S.C. = \left[la(1-\lambda)e^{-rT}(T-v)\right] \qquad \ldots(12)$$

(6) Total Cost: Now total cost of the system can be calculated by summing up all the associated cost of the system:

$$T.C. = \left[PC + OC + HC + SC + LSC\right]$$

$$T.C. = \left\{ca\left[v + \frac{\alpha}{(\beta+1)}v^{(\beta+1)} + \lambda(T-v)e^{-rT}\right] + A\right.$$

$$+ha\left[\frac{v^2}{2} + \frac{\alpha\beta}{(\beta+1)(\beta+2)}v^{(\beta+2)} - \frac{r}{6}v^3 + \frac{\alpha\beta r}{2(\beta+2)(\beta+3)}v^{(\beta+3)}\right]$$

$$\left.+sa\left[\frac{e^{-rv}}{r^2} - \frac{e^{-rT}}{r^2} - \frac{(T-v)e^{-rT}}{r}\right] + \left[la(1-\lambda)e^{-rT}(T-v)\right]\right\} \qquad \ldots(13)$$

From equation (13) we observe that the T.C. is a function of the variable v only and all other parameters are fixed.

The total planning horizon H is a sum of N replenishment cycles, so the total cost for complete planning horizon is given by

$$T.C.' = T.C.\left\{1 + e^{-rT} + e^{-2rT} + e^{-3rT} + \ldots\ldots\ldots + e^{-(N-1)rT}\right\}$$

$$T.C.' = T.C.\left(\frac{1-e^{-rNT}}{1-e^{-rT}}\right) \qquad \ldots(14)$$

This is the objective function for this system and it is clear that the T.C.' is a function of two variables v and N . Here v is a continuous variable and N is a discrete variable. Figure- 2 shows that the T.C. shows the convexity function. Hence the solution obtained will be optimal.

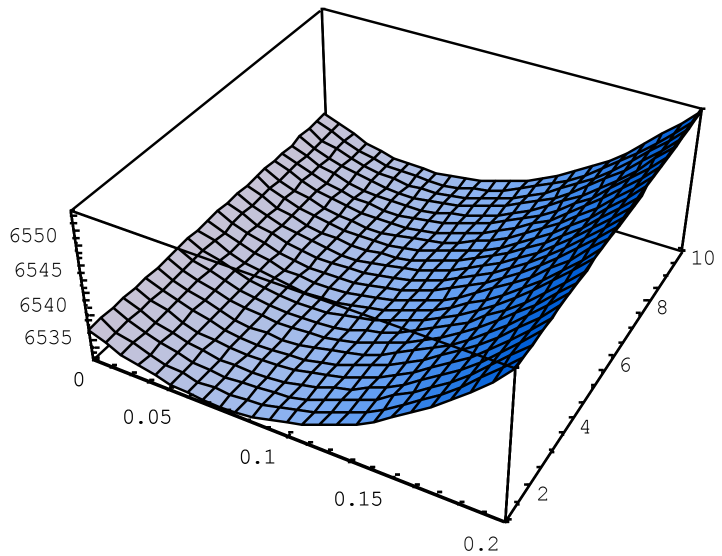

Fig.2: Convexivity of the T.C. function.

V. SOLUTION PROCEDURE

The length of complete planning horizon is H, which is divided into N replenishment cycles. Each replenishment cycle starts with initial inventory level of I_0 units and ends with shortages. After satisfying the occurring demand in the last replenishment cycle the shortages occurs and an extra replenishment to satisfy the backlogged demand in the last cycle is required.

From equation (14) it is obvious that the T.C.' is a function of two variables N and v, where N is a discrete variable and v is a continuous variable. For a particular value of N, the total cost becomes the function of a single variable 'v'. Then to optimize the total cost function, we have

$$\frac{\partial T.C.'}{\partial v} = 0 \qquad \ldots(15)$$

The above mentioned equation for optimality is highly non-linear so these are solved with the help of mathematical software Mathematica 5.2. To arrive at the optimal solution of the system, the following algorithm is presented.

(a) Set the initial value to the number of cycles (N) in the planning horizon (H).

Let N=1, Then T=H/N $\Rightarrow$T=H

(b) Put these values of N and T in equation (15).

(c) Solve equation (15) to find the optimal value of v.

(d) Put this value of v in equation (7) to find out the optimal value of I_0.

(e) Now set N=N+1, and calculate T from T=H/N.

(f) Repeat the steps from (a) to (e) up to the end of cycle.

VI. NUMERICAL EXAMPLE

The following data has been used for the calculation of the equation formed for this system.

$H = 1\,year,\ \ a = 1000\,units,\ \ c = 6\,rs/unit,\ s = 2\,rs/unit,\ \ r = 0.04,\ \ \alpha = 0.001,\ \ \beta = 1.5$

$h = 2\,rs/unit,\ \ l = 2.5\,rs/unit,\ \ \ A = 500\,rs/order,\ \ \ \theta = 0.5$

Table 1: Value of optimal T.C. and initial stock level for fix value of r = 0.04

N	T	V	T.C.	I_0
1	1	0.74118	6574.07	74.1186
2	0.5	0.094991	7145.53	94.9917
3	0.333	0.101951	7659.70	101.952
4	0.25	0.105431	8159.55	105.432
5	0.2	0.10752	8653.67	107.522
6	0.1667	0.108913	9144.92	108.915
7	0.1429	0.109907	9634.54	109.909
8	0.125	0.110653	10124.90	110.655
9	0.1111	0.111233	10611.00	111.235
10	0.1	0.111698	11098.50	111.7

Table 2: Value of optimal T.C. and initial stock level for fix value of r = 0.05

N	T	V	T.C.	I_0
1	1	0.062545	6533.20	62.5458
2	0.5	0.088174	7126.68	88.1749
3	0.333	0.096719	7648.35	96.72
4	0.25	0.100994	8152.09	100.995
5	0.2	0.103559	8648.64	103.56
6	0.1667	0.105269	9141.60	105.27
7	0.1429	0.106491	9632.51	106.492
8	0.125	0.107407	10122.10	107.409
9	0.1111	0.10812	10610.90	108.122
10	0.1	0.10869	11098.40	108.692

For the above mentioned numerical values the model is solved for different values of inflation rate '*r*'. From table 1-2 some interesting facts have been observed which is pointed out as follow:

(i) In both the tables as the value of *T* decreases from 1 to 0.1, the total cost of the system for complete planning horizon goes on increasing and corresponding to these the optimal value of initial inventory level also shows the same effect of increment.

(ii) After comparing both these tables we noticed that as the value of r increases, the optimal value of initial inventory level I_0 shows a decreasing trend and corresponding to it the T. C. of the system also decreases.

VII. SENSITIVITY ANALYSIS

Now we will check the sensitivity of T.C. with respect to different variables taking one at a time for a fix value of 'N=4'.

Table 3: Sensitivity Analysis in T.C. with respect to inflation rate ‘r’:

R	V	T.C.	I_0
0.06	0.096708	11100.4	96.7087
0.07	0.092566	11101	92.5671
0.08	0.088562	11101.4	88.5633
0.09	0.08469	11101.7	84.6908
0.1	0.080943	11101.8	80.9437

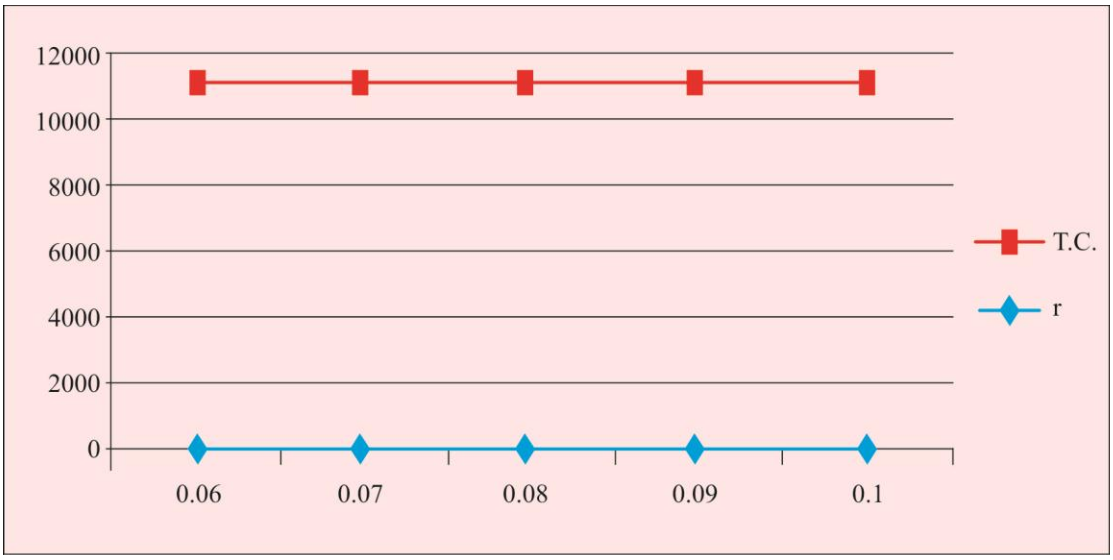

Fig. 3: Sensitivity of T.C. w.r.t. ‘r’

Table 4: Sensitivity Analysis in T.C. with respect to demand parameter ‘a’:

% variation in a	A	V	T.C.	I_0
-20%	800	0.10543	9879.11	83.6251
-15%	850	0.10543	10184.1	88.8517
-10%	900	0.10543	10489	94.0783
-5%	950	0.10543	10793.9	99.3048
0%	1000	0.10543	11098.9	104.531
5%	1050	0.10543	11403.8	109.758
10%	1100	0.10543	11708.8	114.985
15%	1150	0.10543	12013.7	120.211
20%	1200	0.10543	12318.7	125.438

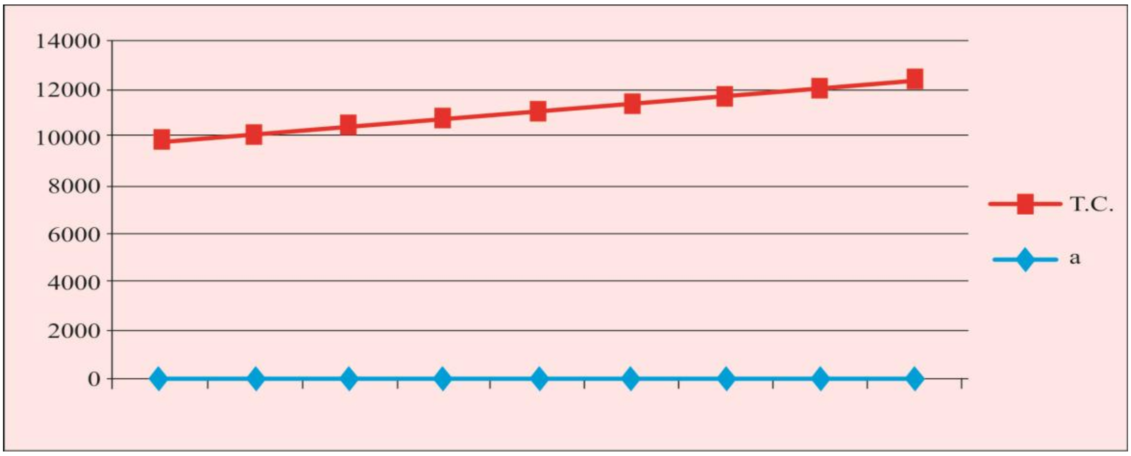

Fig. 4: Sensitivity of T.C. w.r.t. 'a'

Table 5: Sensitivity Analysis in T.C. with respect to deterioration parameter 'α':

% variation in α	A	V	T.C.	I_0
-20%	0.0008	0.1054	8159.54	105.401
-15%	0.00085	0.1054	8159.55	105.401
-10%	0.0009	0.1054	8159.55	105.401
-5%	0.00095	0.1054	8159.55	105.401
0%	0.001	0.1054	8159.55	105.401
5%	0.00105	0.1054	8159.55	105.402
10%	0.0011	0.1054	8159.55	105.402
15%	0.00115	0.1054	8159.56	105.402
20%	0.0012	0.1054	8159.56	105.402

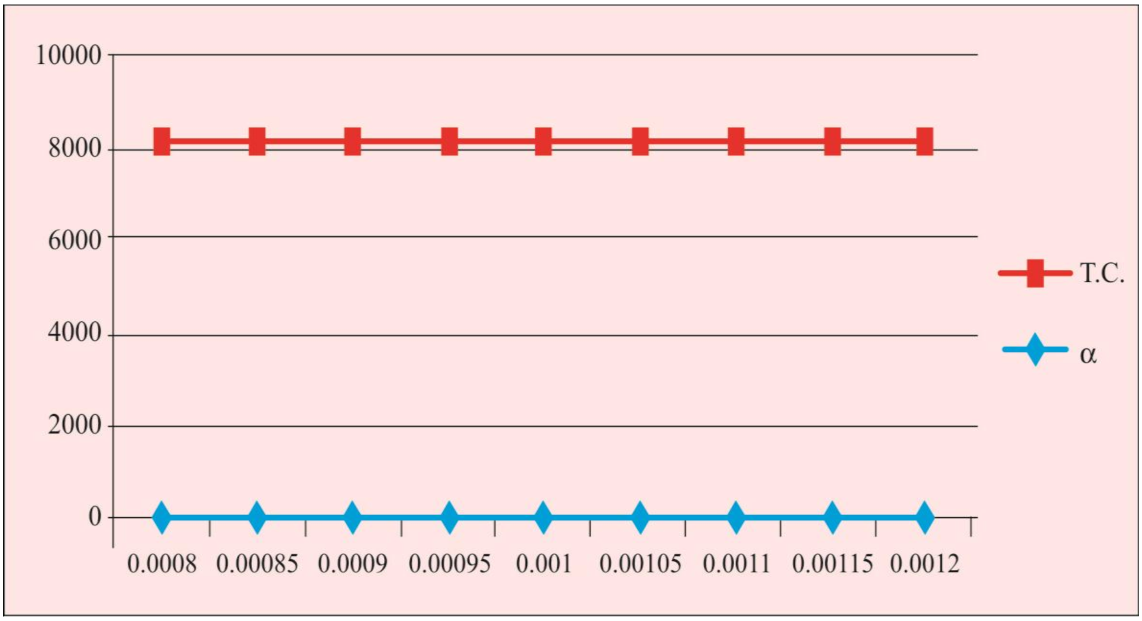

Fig. 5: Sensitivity of T.C. w.r.t. 'α'

Table 6: Sensitivity Analysis in T.C. with respect to deterioration parameter 'β':

% variation in β	B	V	T.C.	I_0
-20%	1.2	0.1053	11099	105.303
-15%	1.275	0.1053	11099	105.303
-10%	1.35	0.1053	11099	105.302
-5%	1.425	0.1053	11098.9	105.302
0%	1.5	0.1054	11098.9	105.401
5%	1.575	0.1054	11098.9	105.401
10%	1.65	0.1054	11098.9	105.401
15%	1.725	0.1054	11098.9	105.401
20%	1.8	0.1054	11098.8	105.401

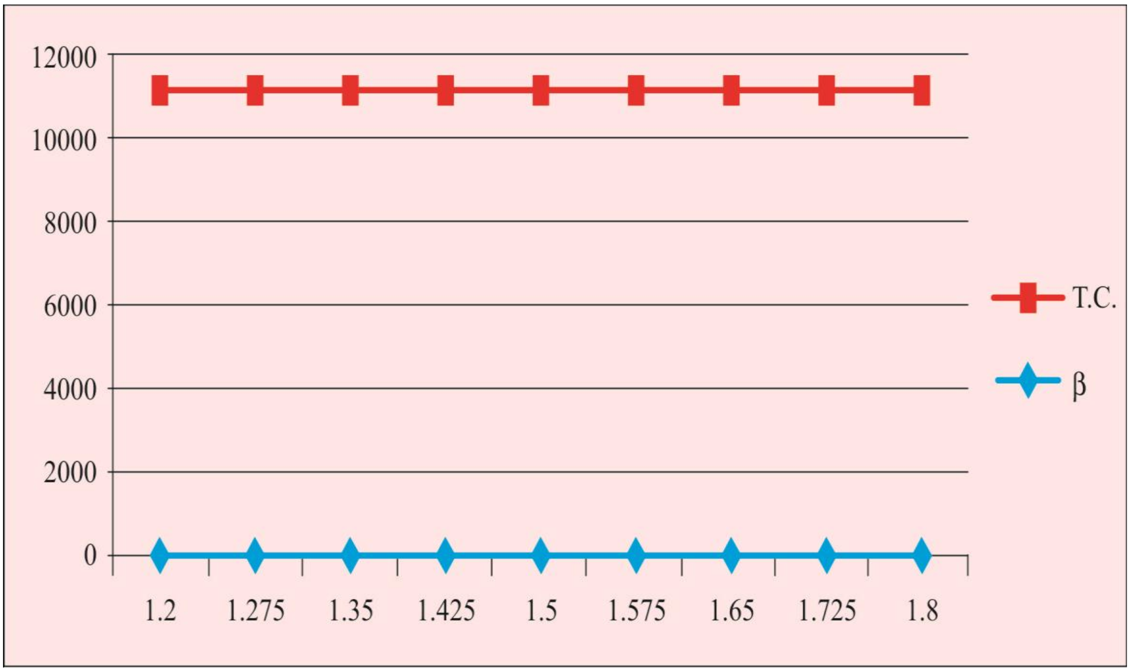

Fig. 6: Sensitivity of T.C. w.r.t. 'β'

Table 7: Sensitivity Analysis in T.C. with respect to backlogging rate 'θ':

% variation in θ	Θ	V	T.C.	I_0
-10%	0.45	0.025116	11048.8	25.116
-5%	0.475	0.06525	11091.4	65.2504
0%	0.5	0.105431	11098.9	105.432
5%	0.525	0.1456	11071.1	145.603
10%	0.55	0.185936	11008	185.906
15%	0.575	0.2262	10909.6	226.21
20%	0.6	0.26664	10775.7	266.655

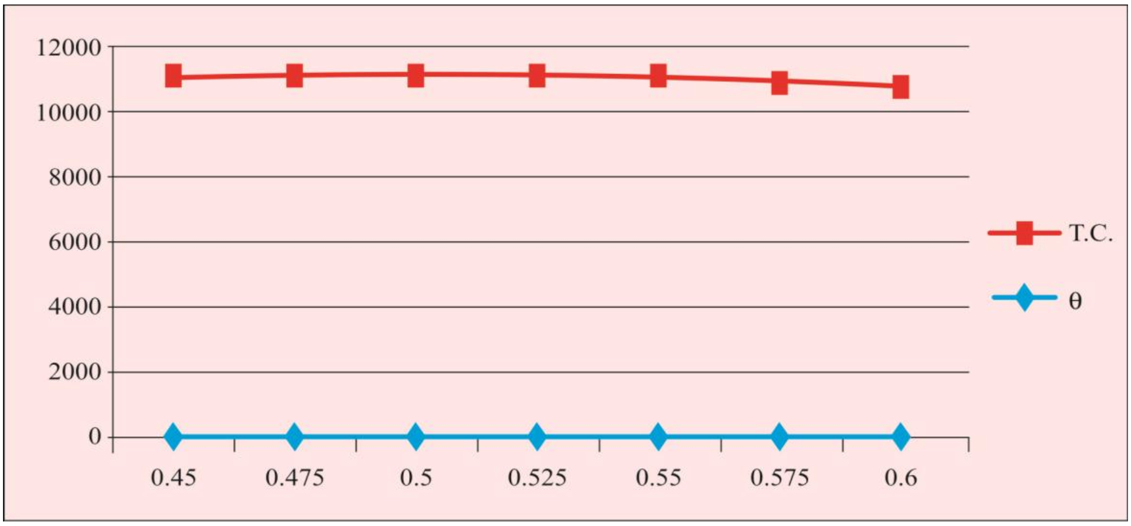

Fig. 7: Sensitivity of T.C. w.r.t. ‘θ’

OBSERVATIONS:

From table 3-7 we have checked the sensitivity of variables r, a, α, β and θ taking one at a time.

(a) Table (3) lists the variation in T.C. with the changes in inflation rate ‘r’. It is obvious from this table that an increment in inflation rate r shows also a trend of continuous increment in T.C. and a nature of decrease in initial stock level.

(b) From table (4) we observe that an increase in demand rate, increases the purchasing cost and hence the T.C. of the system.

(c) In table (5) the variation in deterioration parameter has been listed. It is observed from this table that with the increment in ‘α’ the optimal initial stock level as well as T.C. remains almost unchanged.

(d) From table (6) we observe that an increasing trend in deterioration parameter ‘β’ shows a very slow change in T.C. and initial inventory level I_0. It can be said that the model is quite stable with this parameter.

(e) Table (7) shows that with the increment in backlogging parameter ‘θ’ the ordering quantity increases and so the T.C. of the system.

VIII. CONCLUSION

In this paper an inventory model for deteriorating products under inflationary environment has been developed. The model is developed for finite time horizon. Inflation plays a very significant role in the development of an inventory model. Since the different associated costs changes with time so to develop the inventory models without considering the effect of inflation will mislead the results. Therefore, it should be treated as a permanent parameter in the development of inventory models. Shortages are allowed and assumed to be partially backlogged in this model.

In this new model, we have incorporated the different realistic features such as deterioration, shortages, inflation and partial backlogging in a single model. In this at first the model is developed mathematically and then the optimal solution has been found out. Convexity graph of the model is shown which guarantees for the optimal and unique solution of the T.C. function. The numerical example for the system has been illustrated for different values of replenishment cycle and inflation rate. The sensitivity analysis with respect to different associated parameters is also presented to check the stability of the model and conclusion is made that the model is quite stable and applicable for different domestic products, electronic items and food products. The further extension for this model is possible in the case of variable demand and time dependent rate of backlogging.

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