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An EPQ Model for Deteriorating items with Shortages under Inflation over a Finite Time Horizon

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ABSTRACT: In this paper we have developed a supply chain production inventory model for deteriorating items and simultaneously considered the inflation and time value of money when shortages are allowed over a finite planning horizon. Demand is assumed to be known and constant. In addition, the effects of inflation and time value of money on production system under instantaneous replenishment of raw materials with zero lead-time are also considered. The necessary and sufficient conditions for an optimal solution are characterized. The formulae for the optimal present value of total system cost over a finite planning horizon, backlog level and production cycle time are derived when the deterioration rate is very small. Our approach is illustrated through a numerical example to demonstrate the application and the performance of the proposed methodology. Sensitivity analysis is carried out to demonstrate the effects of changing parameter values on the optimal solution of the system.

KEYWORDS: EPQ, Deterioration, shortage, Finite time horizon, Inflation

I. INTRODUCTION

In recent years, the control and maintenance of production inventories of deteriorating items with shortages have attracted much attention in inventory analysis because most physical goods deteriorate over time. The effect of deterioration is very important in many inventory systems. Deterioration is defined as decay or damage such that the item can not be used for its original purpose. Food items, drugs, pharmaceuticals, radioactive substances are examples of items in which sufficient deterioration can take place during the normal storage period of the units and consequently this loss must be taken into account when analyzing the system. The first attempt to describe the optimal ordering policies for deteriorating items with a linear trend in demand was made by T. Chakrabarti, K.S. Chaudhury, (1997) (1). A detailed review of deteriorating inventory literatures is given by T. Chakrabarti, B.C. Giri, K.S. Chaudhury: (1998) (2). They developed an EOQ model for items with Weibull distribution deterioration, shortages and trended demand. N. K. Duari et al. (2015) (3) defined a production inventory model with deterioration. S. sarkar and T. Chakrabarti (2012) (4) developed an inventory model of instantaneous deteriorating items with fuzzy Ramp-type demand allowing backlogging. Sarkar and Chakrabarti (2010) (5) presented an EPQ model with demand dependent production and Weibull distribution for deteriorating items. Mishra and Shah (2008) (6) developed an inventory management of time dependent deterioration with salvage value. S. Sarkar et al. (2011) (7) proposed an EPQ Model for deteriorating items having weibull distribution deterioration with time dependent demand, holding cost and shortage cost. S sarkar and T Chakrabarti (2011) (8) studied a two-echelon supply chain model for deteriorating items with time dependent demand, demand dependent production rate and shortage. N.K. Duari and T Chakrabarti (2014) (9) developed an order level EOQ model for deteriorating items in a single warehouse system with price dependent demand and shortages. S Saha and T Chakrabarti (2013) (10) presented a two- echelon supply chain model for deteriorating product with time dependent demand, demand dependent production rate and shortage. Several researchers like S Saha et al. (2017) (14), Bera, S., Kar, S., Chakraborti, T. and Sinha, B. (2014) (15), Sujata Saha and T Chakrabarti (2018) (16) have developed different types of inventory model for deteriorating items.

Inflation plays an essential role for the optimal order policy and influences the demand of certain products. As inflation increases, the value of money goes down and erodes the future worth of saving and forces one for more current spending. Usually, these spending are on peripherals and luxury items that give rise to demand of these items. As a

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result, the effect of inflation and time value of the money cannot be ignored for determining the optimal inventory policy. As mentioned above, inflation has a major effect on the demand of the goods, especially for fashionable goods for middle and higher income groups. The concept of the inflation should be considered especially for long term investment and forecasting. Buzacott (1975) (11) first developed the EOQ model taking inflation into account. Bierman and Thomas (1977) (12) investigated an inventory decision under inflationary conditions. Misra (1979) (13) then extended the EOQ model with different inflation rates for various associated costs. N.K. Duari, T Chakrabarti (2015) (17) developed a fuzzy EOQ model with reserve money for in an inflationary environment under supplier credits. Sumana Saha and T Chakrabarti (2019) (18) provided an EOQ model for deteriorating items with price and stock-dependent selling rates under inflation and time value of money. Hou and Lin (2006) (19) developed an EOQ model for deteriorating items with price and stock dependent selling rates under inflation and time value of money. S Kundu and T Chakrabarti (2018) (20) analyzed a fuzzy rough integrated multi-stage supply chain inventory model with carbon emissions under inflation and time-value of money. Several researchers like C.T. Chang (2004)(21), Liao, H.C., Tsai, C.H., Su, C.T.: (2000) (22), Moon, I.and Lee, S. (2000) (23), Roy, A., Maiti, M.K., Kar, S., Maiti, M. (2009) (24), Sana, S. and Chaudhuri, K. (2003) (25), Sarker, B.R., Jamal, A.M.M., Wang, S. (2000) (26) and Singh, S.R., Singh, C., (2010) (27) have developed different types of inventory model under inflation and time value of money.

In the present paper we have developed a continuous production control inventory model for deteriorating items and simultaneously considered the inflation and time value of money when shortages are allowed over a finite planning horizon. It is assumed that the demand rate and production rate are constants. In addition, the effects of inflation and time value of money on replenishment policy under instantaneous replenishment are also considered. The main focus is on the structural behavior of the system. The convexity of the present value of cost function is established to ensure the existence of a unique optimal solution. The optimum inventory level is proved to be a decreasing function of the deterioration rate where the deterioration rate is taken as very small. The formulae for the optimal cost, Cycle time, backlog level are derived when the deterioration rate is very small over a finite planning horizon. An optimization framework is presented to derive optimal replenishment policy when the present value of total cost is minimized. Numerical examples are taken and the sensitivity analysis is carried out to demonstrate the effects of changing parameter values on the optimal solution of the system. The problem is solved by using LINGO 17.0 software.

Mathematical Preliminary:

- **Inflation:**

Inflation is a persistent increase in the level of consumer prices or a persistent decline in the purchasing power of money, caused by an increase in available currency and credit beyond the proportion of available goods and services. It is the rate at which the general level of prices for the goods and services is rising and subsequently, purchasing power of is falling. With the increase of inflation rate, more amount of money is to be paid for the same quantity of commodity. For example, if the inflation rate is 2%, then a $1 pack of gum will cost $1.02 in a year.

- **Time value of Money:**

The basic principle, that money can earn interest, so something that is worth $1 today will be worth more in the future if invested. This is also referred to as future value. For example,
$1 today, invested at 5% return, would be worth $1.05 in one year.
The time value of money (TVM) or the present discounted value is one of the basic concepts of finance. We know that if we deposit money in the bank we will receive interest. Because for this, we prefer to receive money today rather than the same amount in the future. Money we receive today is more valuable to us than money receive in the future by the amount of interest we can earn with the money. This is referred to as the time value or cash value of money. It is the changes in purchasing power of money over time. There are two formulas:

➢ Let the money carry a rate of interest r per year. Thus, a rupee will be worth $(1+r)$ after a year, $(1+r)^2$ after two years, and so on. In this way a rupee today will be worth $(1+r)^n$, n years hence, or, in other words if we have to make a payment of one rupee in n years time, it is equivalent to making a payment of $(1+r)^{-n}$ rupees today. The quantity $(1+r)^{-n}$ is called the present worth factor (Pwf) of one rupee spent in n years time from now onwards. The expression $(1+r)^n$ is known as the payment compound amount factor (Caf) of one rupee spent in n years time.

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- **Present Value Formula:**

It is used to discount future money streams: that is, to convert future amounts to their equivalent present day amounts

$$\text{Present Value} = \frac{\text{Future Value}}{(1 + \text{Interest Rate})^{\text{term}}}$$

- **Future Value Formula:**

It is used to convert today's money into the equivalent amount at some time in the future.

$$\text{Future Value} = \text{Present Value X } (1 + \text{Interest Rate})^{\text{term}}$$

Discounting is the process of finding the current value of an amount of cash at some future date, and along with compounding cash from the basis of time value of money calculations. The discounted value of cash flow is determined by reducing its value by the current discount rate for each unit of time between the times when the cash flow is to be valued to the time of cash flow. Most often the discount rate is expressed as an annual rate. The discount factor, P(T), is the number by which a future cash flow to be received at time T must be multiplied in order to obtain the current present value.

Thus for a fixed annually compounded discount rate r $P(T) = 1/(1+r)^T$

And for a fixed continuously compounded discount rate r we have $P(t) = e^{-rt}$

II.NOTATION AND ASSUMPTIONS

The following notations and assumptions are used for developing the model.

(a) a = the constant demandrate.
(b) $p (> a)$ = the constant production rate.
(c) θ = the deterioration rate $(0 < \theta < 1)$
(d) T = length of the order cycle
(e) r = discount rate, representing the time value of money
(f) f = inflation rate
(g) $R = r - f$, representing the net discount rate of inflation is constant
(h) H = the planning horizon
(i) N = number of order cycle during the planning horizon
(j) T_j = the total time that is elapsed up to and including the jth order cycle (j = 1, 2, … ,N), where $T_O = 0, T_1 = T, \ldots, T_N = H$
(k) C_1 = the holding cost per unit per unit time.
(l) C_2 = the shortage cost per unit per unit time.
(m) C_3 = the cost of a deteriorated unit. (C_1, C_2 and C_3 are known constants).
(n) $Q(t)$ = the on-hand inventory at time t $(0 \leq t \leq T)$.
(o) TC_F = the total cost for first ordercycle.
(p) TC = the total cost of the system over a finite planning horizon H.
(q) A single item is considered over the prescribed period of planning horizon.
(r) Replenishment is instantaneous and lead time is zero.
(s) Shortages are allowed and backlogged.
(t) It is assumed that no repair or placement of the deteriorated items takes place during a given cycle.
(u) The effects of inflation and time value of money are considered.

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Suppose that the planning horizon H is divided into N equal parts of length $T = H/N$. Hence the reorder times over the planning horizon H are $T_j = jT, (j = 0,1,2, \ldots, N)$. For every order cycle of length T the production starts at time $t = 0$ and stops at time $t = t_1$. During $[0, t_1]$, the production rate is p and the demand rate is a ($< e$). The stock attains a level Q_1 at time $t = t_1$. During $[t_1, t_2]$, the inventory level gradually decreases mainly to meet demands and partly for deterioration. The stock falls to the zero level at time $t = t_2$. Now shortages occur and accumulate to the level Q_2 at time $t = t_3$. The production starts again at a rate e at $t = t_3$and the backlog is cleared at time $t = T$ when the stock is again zero. The cycle then repeats itself after time T.

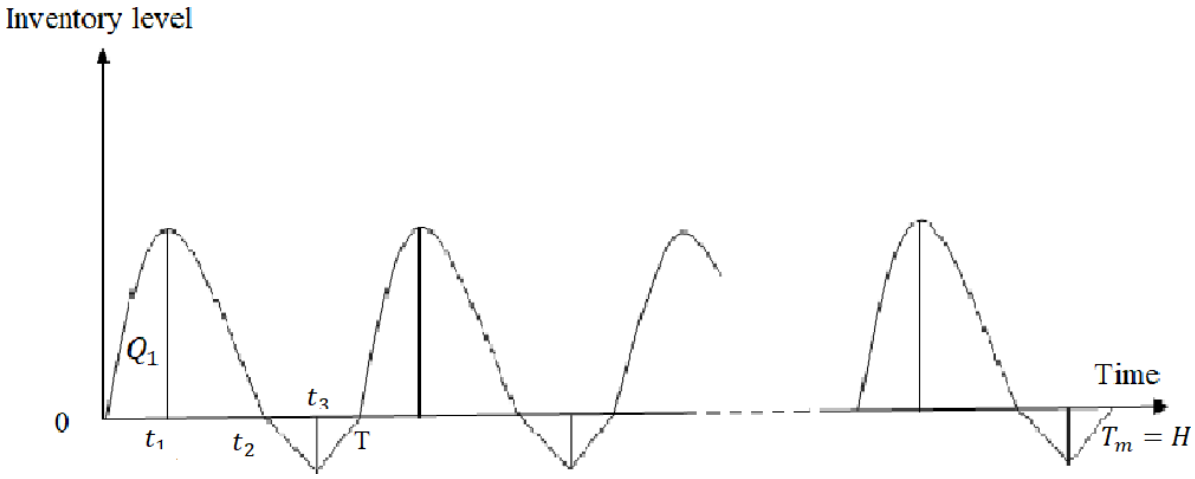

Fig. 1 Graphical representation of the Inventory system

III. MATHEMATICAL MODEL

Based on the above description ,for every order cycle of length T the differential equations governing the instantaneous state of Q(t) at any time t are given by

$\frac{dQ(t)}{dt} + \theta Q(t) = p-a$, $0 \le t \le t_1$ ----------(1)

$\frac{dQ(t)}{dt} + \theta Q(t) = -a$, $t_1 \le t \le t_2$ ----------(2)

$\frac{dQ(t)}{dt} = -a$, $t_2 \le t \le t_3$ ----------(3)

$\frac{dQ(t)}{dt} = p - a$, $t_3 \le t \le T$ ----------(4)

The boundary conditions are

$Q(0)=0, Q(t_1)=Q_1, Q(t_2)=0, Q(t_3)= - Q_2, Q(T) =0$ ----------(5)

The solution of equations (1)-(4) are given by

$Q(t)= \frac{1}{\theta}(p-a)(1-e^{-\theta t})$, $0 \le t \le t_1$ ----------(6)

$= -\frac{a}{\theta} + (Q_1+\frac{a}{\theta})e^{\theta(t1-t)}$, $t_1 \le t \le t_2$ ----------(7)

$= a(t_2-t)$, $t_2 \le t \le t_3$ ----------(8)

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$= (p-a)(t-t_3) - Q_2,\ t_3 \le t \le T$ ----------(9)

From (5) and (6) ,we have

$Q_1 = Q(t_1) = \frac{1}{\theta}(p-a)(1-e^{-\theta t1})$

Which implies,

$e^{\theta t1} = [\,1 - \frac{\theta Q1}{(p-a)}\,]^{-1}$

$t_1 = \frac{1}{\theta}\log[1+(\frac{\theta Q1}{(p-a)} + \frac{\theta^2 Q1^2}{(p-a)^2})]$----------(10a)

$= \frac{Q1}{(p-a)} + \frac{\theta Q1^2}{(p-a)^2}$ ---------- (10b) (neglecting higher power of θ, (0 < θ <<1)

Again from (5) and (7) , we have

$0 = Q(t_2) = -\frac{a}{\theta} + (Q_1 + \frac{a}{\theta})\,e^{\theta(t1-t2)}$ ---------- (11)

$t_2 = \frac{1}{\theta}\log[(1+\frac{\theta Q1}{a})(1 + \frac{\theta Q1}{(p-a)} + \frac{\theta^2 Q1^2}{(p-a)^2})]$ (using (10)) ----------(12)

Using the condition $Q(t_3) = -Q_2$, we have from (8)

$a(t_2-t_3) = -Q_2$

$t_3 = \frac{Q2}{a} + t_2$ ----------(13)

$t_3 = \frac{Q2}{a} + \frac{1}{\theta}\log[(1+\frac{\theta Q1}{a})(1 + \frac{\theta Q1}{(p-a)} + \frac{\theta^2 Q1^2}{(p-a)^2})]$ ----------(14)

From (9) and Q(T)=0 ,we have

$(p-a)(T-t_3) = Q_2$ ----------(15)

From (14) and (15) we have ,

$Q_2 = \frac{aT(p-a)}{p} - Q_1 - \frac{\theta Q1^2(2a-p)}{2a(p-a)}$ ----------(16)

Therefore total deterioration in (0,T)

$= [(p-a)t_1 - Q_1] + [Q_1 - a(t_2-t_1)]$

$= [\frac{(p-a)}{\theta}\log[1 + \left(\frac{\theta Q1}{(p-a)} + \frac{\theta^2 Q1^2}{(p-a)^2}\right) - Q1\,] + [Q1 - \frac{a}{\theta}\log[1 + \frac{\theta Q1}{a}]$

$= \frac{\theta Q1^2 p}{2a(p-a)}$ (Neglecting higher power of θ) ----------(17)

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The deterioration cost DC during first order cycle is

$DC = C_3 \int_0^{t2} \frac{\theta Q1^2 p}{2a(p-a)} e^{-Rt}\, dt$

$= C_3 \frac{\theta Q1^2 p}{2a(p-a)R} (1-e^{-Rt2})$ ---------- (18)

The shortage cost SC during the first order cycle is

$SC = C_2 \int_{t2}^{T} \{-Q(t)\} e - Rtdt$

$= -C_2 [\int_{t2}^{t3} a\,(t2 - t) e - Rtdt + \int_{t3}^{T} \{(p - a)(t - t3) - Q2\} e - Rtdt]$

$= \frac{c2}{R^2} [\,(p-a)\, e^{-RT} - p\, e^{-Rt3} + a e^{-Rt2}]$ ----------(19)

Inventory holding cost HC during the first order cycle is

$HC = C_1 \int_0^{t2} Q(t)\, e^{-Rt}\, dt$

$= C_1[\int_0^{t1} \frac{(p-a)}{\theta} (1 - e - \theta t) e^{-Rt}\, dt] + C_1 [\int_{t1}^{t2} \{-\frac{a}{\theta} + (Q1 + \frac{a}{\theta}) e^{\theta(t1-t)}\} e^{-Rt}\, dt]$-----(20)

Now, $\int_0^{t1} \frac{(p-a)}{\theta} (1 - e - \theta t) e^{-Rt}\, dt$

$= \frac{(p-a)}{\theta} \{ \frac{e^{-(\theta+R)t1}}{(\theta+R)} - \frac{e^{-Rt1}}{R} + \frac{\theta}{R(\theta+R)} \}$ ----------(21)

Therefore , the inventory holding cost HC during first cycle is

$HC = \frac{C1}{R(\theta+R)} [a e^{-Rt2} - p e^{-Rt1} + (p-a)]$ ----------(22)

So, the total cost for the first order cycle is formulated as (using (18),(19). And (22))

$TC_F = HC + SC + DC$

$= \frac{C1}{R(\theta+R)} [a e^{-Rt2} - p e^{-Rt1} + (p-a)] + \frac{c2}{R^2} [\,(p-a)\, e^{-RT} - p\, e^{-Rt3} + a e^{-Rt2}] + C_3 \frac{\theta Q1^2 p}{2a(p-a)R} (1-e^{-Rt2})$ -

----------(23)

Therefore the present value of total cost of the system over a finite horizon H is

$TC(m,T) = \sum_{J=0}^{m-1} TC_F\, e^{-\frac{R}{T}} = TC_F (\frac{1 - e - RH}{1 - e - RH/m})$ where $T = \frac{H}{M}$

On simplification ,we get

$TC(m,T) = [\frac{C1}{R(\theta+R)} [a e^{-Rt2} - p e^{-Rt1} + (p-a)] + \frac{c2}{R^2} [\,(p-a)\, e^{-RT} - p\, e^{-Rt3} + a e^{-Rt2}] + C_3 \frac{\theta Q1^2 p}{2a(p-a)R} (1-e^{-Rt2})$

$] (\frac{1 - e - RH}{1 - e - RH/m})$ ----------(24)

The present value of total cost TC(m,T) is a function of two variables of m and T where m is a discrete variable and T is a continuous variable.

For a given value of m, the necessary condition for TC(m,T) to be minimized is

$d\,TC(m,T)/dT = 0$ ----------(25)

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So for a given positive integer m, the optimum value of T(sayT^*) can be obtained from equation no (25)

Furthermore , $d^2TC(m,T)/dT^2 > 0$ for $T=T^*$,thenT^* will be an optimal solution
Hence , TC(m,T) is strictly convex function of T
Substituting the value of $T=T^*$ in (24) , the optimal present value of total cost $TC^*(m^*,T^*)$ over a finite planning horizon H can be determined

IV. NUMERICAL EXAMPLES

Here we have calculated optimal production cycle length T^*, blocking level Q_2^* and number of order cycle m^* and the minimum total cost TC^*over a finite planning horizon H for given values of other parameters by considering example.

Example:

We consider the following numerical values of the parameters in appropriate units to analyze the model:

θ= 0.0004, C_1=4, C_2=20, C_3=40, P=20, a=8, R=.2 and H=800 in appropriate units.

We obtained ,

T^*=13.69,Q_2^*=5.73,m^*=58(approx.),TC^*=601.07

V. SENSITIVITY ANALYSIS

The sensitivity analysis is performed by changing the value of each of the parameters θ, C_1, C_2, C_3, e,a, R and Q_1 taking one parameter at each time and keeping the remaining parameters unchanged. We now study sensitivity of the optimal solution to changes in the values of the different parameters associated with the model.

Table 1: Sensitivity on 'θ'

Parameter	Change value	N	T	Q_2	TC
θ	0.0002	59	13.66	5.60	586.44
	0.0003	58	13.67	5.66	593.76
	0.0005	58	13.70	5.80	608.38
	0.0006	58	13.72	5.86	615.68

Table 2: Sensitivity on 'C_1'

Parameter	Change value	N	T	Q_2	TC
C_1	2	61	13.14	3.09	316.79
	3	60	13.42	4.42	459.21
	5	57	13.95	7.10	742.39
	6	56	14.21	8.24	883.24

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Table 3: Sensitivity on 'C_2'

Parameter	Change value	N	T	Q_2	TC
C_2	14	56	14.16	8.10	598.91
	17	57	13.88	6.68	600.15
	23	59	13.54	5.02	601.77
	26	60	13.42	4.46	602.32

Table 4: Sensitivity on 'C_3'

Parameter	Change value	N	T	Q_2	TC
C_3	30	58	13.67	5.66	593.71
	35	58	13.68	5.70	597.39
	45	58	13.69	5.76	604.75
	50	58	13.70	5.80	608.43

Table 5: Sensitivity on 'p'

Parameter	Change value	N	T	Q_2	TC
e	16	49	16.27	5.07	540.58
	18	54	14.72	5.45	575.91
	22	61	12.94	5.94	619.79
	24	64	12.39	6.10	634.23

Table 6: Sensitivity on 'a'

Parameter	Change value	N	T	Q_2	TC
a	7	55	14.48	5.96	623.82
	9	60	13.23	5.52	580.20
	10	61	13.06	5.31	560.10
	11	62	12.9	5.10	539.74

Table 7: Sensitivity on 'R'

Parameter	Change value	N	T	Q_2	TC
R	0.1	58	13.75	6.06	1241.01
	0.3	59	13.59	5.20	370.16
	0.4	59	13.46	4.62	249.88
	0.5	60	13.34	4.09	178.17

Table 8: Sensitivity on 'Q_1'

Parameter	Change value	N	T	Q_2	TC
Q_1	56	63	12.78	5.38	563.39
	58	60	13.24	5.56	582.03
	62	57	14.14	5.90	619.60
	64	55	14.59	6.06	637.91

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Observation:
The following are noted on the basis of the sensitivity analysis-

i) From table 1 the observation can be made as, when the deterioration rate 8 is increasing (or decreasing), the present value of total cost TC is increasing (or decreasing). Here, TC is moderately sensitive to change in 8.

ii) From Table 2, 3 and 4 it is observed that, increase (or decrease) of the various cost C_1, C_2, and C_3, the present value of total inventory cost TC also increase (or decrease). Also we observed that TC is highly sensitive to change in 'C_1', but moderately sensitive to change in C_2andC_3.

iii) When production rate e decreases or increases, the backorder level Q_2 and the present value of total cost TC will also decrease or increase and the backorder level Q_2 and the present value of total cost TC will also increase or decrease as demand rate a decreases or increases. That is, the changes in e will lead to the positive changes in Q_2 and TC but the changes in a will lead to the negative changes in Q_2 and TC. (From table 5 and 6).

iv) The change in net discount rate of inflation R leads to a negative change in the present value of total cost TC and the backorder level Q_2 i.e., when R increases, TC and Q_2will also decrease. Here, TC is highly sensitive to change in R. (From table 7).

v) As the stock level Q_1 increases (or decrease) we observed that the backorder level Q_2 and the present value of total cost TC increases (or decrease). Here also Q_2 and TC are moderately sensitive due to change in 'Q_1'. (From table 8).

VI. CONCLUSION

In this study, a production inventory model was developed over a finite planning horizon for deteriorating item with shortages under inflation and time-value of money. It is assumed that the demand and production rates are constant and the distribution of the time to deterioration of an item follows the exponential distribution. This model incorporates some realistic features that are likely to be associated with some kinds of inventory. Deterioration over time is a natural feature for goods. Occurrence of shortages in inventory is a natural phenomenon in real situations. Next, since the inventory systems always need to invest large capital to purchase inventories, which it is highly correlated to the return of investment. Hence, it is important to consider the effects of inflation and the time value of money in formulating inventory replenishment policy. In keeping with this reality, these factors are incorporated into the present model. This model is applicable for food items, drugs, pharmaceuticals. Here we have studied the structural properties of this inventory system.
We have given an analytic formulation of the problem on the framework described above and have presented an optimal solution procedure to find optimal present value of the total cost TC. By constructing an efficient computational algorithm, we illustrated through an example that how the optimal back order level and present value of total cost can be derived. Finally, the sensitivity of the solution to changes in the values of different parameters has been discussed.

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