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## Mathematical Production Inventory Model for Deteriorating Items with Stock and Time Dependent Demand, Time Varying Holding Cost and Shortages in a Fuzzy Environment

P. Anitha, P. Parvathi

Assistant Professor, Department of Mathematics, Quaid- E -Millath Government College for Women, Chennai, Tamil  
Nadu, India.

Principal, Government Arts College, Paramakudi, Tamil Nadu, India

**ABSTRACT:** This study develops an EPQ model for deteriorating items assuming time and stock dependent demand and time varying holding cost under the effect of inflation in fuzzy environment. Shortages are allowed and partially backlogged. In finding the optimal production quantity, deterioration plays a crucial role in inventory management. Therefore handling of deterioration is in highlight and attracted many researchers. Deterioration means decay, damage or spoilage such that the item cannot be used for its original purpose. To retain the confidence of the buyers the machine reliability, flexibility and packaging cost are considered. Mathematical model has been presented to find the optimum total cost. The holding cost, setup cost, deterioration cost, labour cost for packing, material cost for packing, shortage cost, production cost involved in this model are taken as triangular fuzzy numbers. To validate the optimal solution, numerical example is provided. Sensitivity analysis is carried out to explore the effect of changes in the values of different parameters.

**KEYWORDS:** Deteriorating items, Shortages, Reliability, Flexibility and Triangular fuzzy number.

### I. INTRODUCTION

EPQ is very important from the inventory management point of view since holding too much inventory is costly to carry while holding too little can result in stock outs, lost sales and can impact brand value. Deterioration is defined as damage, spoilage, decay etc. which decreases the usefulness of the commodity. Deterioration has been widely studied in the recent times owing to its huge impact on the overall profitability on an inventory system. In this paper an EPQ model for deteriorating items is derived to minimize the total cost and to find the optimal production quantity. Here the demand rate and production rate both considered to be stock and time dependent. Also holding cost is time dependent. Shortages are considered which are partially backlogged and the holding cost, setup cost, deterioration cost, labour cost for packing, material cost for packing, shortage cost, production cost involved in this model are taken as triangular fuzzy numbers. Promoting the production of the product serves as the ultimate target of the manufacturer. To make the rate of production fast, the machines are subjected to continuous wear and tear which results in depreciation. To withstand these circumstances the manufacturers have to maintain high degree of reliability and flexibility. This paper elucidates about packaging, comprises the formulation of an EPQ model with the inclusion of package cost. Objective of this work is to minimize the total cost and finding the optimal production quantity.

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## II. LITERATURE REVIEW

Harries [1] studied EOQ (Economic Order Quantity) model and derived some useful results. After that Taft [2] presented EPQ (Economic Production Quantity) formula. Many inventory models in the inventory literature were presented considering time- dependent demand. Silver and Meal [3] were first presented an EOQ model for the case of the time varying demand. Donaldson [4] developed an inventory model with linearly time dependent demand. Teng et al. [5] established inventory model under trade credit financing with increasing demand. Khanra et al. [6] presented an inventory model for deteriorating item with time- dependent demand. Teng et al. [7] developed an EOQ model for increasing demand in a supply chain with trade credits. Large number of research papers presented by authors like Dave and Patel [8], Jalan and Chauduri [9], Jalan et al. [10], Mitra et al. [11] in this direction. Samanta and Roy [12] established a continuous production inventory model of deteriorating item with shortages and considered that the production rate is changed to another at a time when the inventory level reaches a prefixed level. Hou [13] established an EPQ model with imperfect production process, in which the setup cost is a function of capital expenditure. Cardenas- Barron [14] presented an Economic Production Quantity (EPQ) inventory model with planned backorders for deteriorating the Economic Production Quantity for a single product. Cardenas- Barron [15] established an EPQ model with production capacity limitation and breakdown with immediate rework. Krishnamoorthi et al. [16] established a single stage production process where defective item produced are reworked and two models of rework process are considered, an EOQ model for with and without shortages. Recently, Liu et al. [17] established the problem of a production system that can produce multiple products but also subject to preventive maintenance at the setup times of some products. Taleizadeh et al. [18] developed a vendor managed inventory for two level supply chain comprised of one vendor and several non- competing retailers, in which both the raw material and the finished product have different deterioration rates. Ghiami and Williams [19] established a production- inventory model in which a manufacturer is delivering a deteriorating product to retailers. Dr. Neeraj Agarwal [19] has developed an EPQ model with time dependent demand and reduction delivery policy. Parvathi et al [20] have developed an EPQ model for deteriorating items with time dependent demand with Reliability and Flexibility in a Fuzzy environment. This paper is based on [20] with stock and time dependent demand and time varying holding cost in a fuzzy environment. We have taken holding cost, setup cost, shortage cost, production cost, deterioration cost, labour cost for packing material cost for pack as triangular fuzzy number. We defuzzify the above cost using signed distance method.

## III. PRELIMINARY CONCEPTS

**3.1 Fuzzy Numbers:** Any fuzzy subset of the real line  $R$ , whose membership function  $\mu_A$  satisfied the following conditions, is a generalized fuzzy number  $\tilde{A}$ .

(i)  $\mu_A$  is a continuous mapping from  $R$  to the closed interval  $[0, 1]$ ,

(ii)  $\mu_A = 0, -\infty < x \leq a_1$

(iii)  $\mu_A = L(x)$  is strictly increasing on  $[a_1, a_2]$

(iv)  $\mu_A = w_A, a_2 \leq x \leq a_3$

(v)  $\mu_A = R(x)$  is strictly decreasing on  $[a_3, a_4]$

(vi)  $\mu_A = 0, a_4 \leq x \leq \infty$

Where  $0 < w_A \leq 1$  and  $a_1, a_2, a_3$  and  $a_4$  are real numbers. Also this type of generalized fuzzy number be denoted as

$\tilde{A} = (a_1, a_2, a_3, a_4; w_A)_{LR}$ ; when  $w_A = 1$ , it can be simplified as  $\tilde{A} = (a_1, a_2, a_3, a_4; w_A)_{LR}$ .

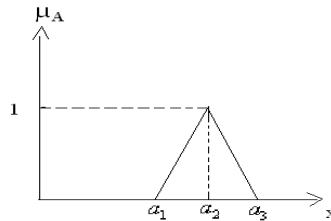
**3.2 Triangular fuzzy number:** The fuzzy set  $\tilde{A} = (a_1, a_2, a_3)$  where  $a_1 < a_2 < a_3$  and defined on  $R$ , is called the triangular fuzzy number, if the membership function of  $\tilde{A}$  is given by

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$$\mu_A = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2 \\ \frac{a_3 - x}{a_3 - a_2}, & a_2 \leq x \leq a_3 \\ 0, & \text{otherwise} \end{cases}$$



**3.3 The Function Principle:** The function principle was introduced by Chen [6] to treat fuzzy arithmetical operations. This principle is used for addition, subtraction, multiplication and division of fuzzy numbers.

Suppose  $\tilde{A} = (a_1, a_2, a_3)$  and  $\tilde{B} = (b_1, b_2, b_3)$  are two triangular fuzzy numbers. Then

(i) The addition of  $\tilde{A}$  and  $\tilde{B}$  is

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \text{ where } a_1, a_2, a_3, b_1, b_2, b_3 \text{ are any real numbers.}$$

(ii) The multiplication of  $\tilde{A}$  and  $\tilde{B}$  is  $\tilde{A} \times \tilde{B} = (c_1, c_2, c_3)$

where  $T = (a_1b_1, a_1b_3, a_3b_1, a_3b_3)$ ,  $c_1 = \min T$ ,  $c_2 = a_2b_2$ ,  $c_3 = \max T$  if  $a_1, a_2, a_3, b_1, b_2, b_3$  are all non zero positive real numbers, then  $\tilde{A} \times \tilde{B} = (a_1b_1, a_2b_2, a_3b_3)$ .

(iii)  $-\tilde{B} = (-b_3, -b_2, -b_1)$  then the subtraction of  $\tilde{B}$  from  $\tilde{A}$  is  $\tilde{A} - \tilde{B} = (a_1 - b_3, a_2 - b_2, a_3 - b_1)$  where  $a_1, a_2, a_3, b_1, b_2, b_3$  are any real numbers.

(iv)  $\frac{1}{\tilde{B}} = \tilde{B}^{-1} = (\frac{1}{b_3}, \frac{1}{b_2}, \frac{1}{b_1})$  where  $b_1, b_2, b_3$  are all non-zero positive real numbers, then the division of  $\tilde{A}$  and  $\tilde{B}$  is

$$\frac{\tilde{A}}{\tilde{B}} = (\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1})$$

(v) For any real number  $K$ ,  $K\tilde{A} = (Ka_1, Ka_2, Ka_3)$  if  $K > 0$

$$K\tilde{A} = (Ka_3, Ka_2, Ka_1) \text{ if } K < 0$$

**3.4. Signed Distance Method:** Defuzzification of  $\tilde{A}$  can be found by signed distance method. If  $\tilde{A}$  is a triangular fuzzy number and is fully determined by  $(a_1, a_2, a_3)$ , the signed distance from  $\tilde{A}$  to 0 is defined as

$$d(\tilde{A}, \tilde{0}) = \int_0^1 d([A_L(\alpha), A_R(\alpha)], \tilde{0}) d\alpha = \frac{(a_1 + 4a_2 + a_3)}{4}$$

### IV. NOTATIONS AND ASSUMPTIONS

The following notations and assumptions have been used to develop the fuzzy mathematical model.

#### 4.1 NOTATIONS

$I(t)$	Inventory level at anytime 't'
$T$	cycle time
$T_1$	production time per unit per unit time
$T_2$	The time at which the shortage begins
$I_1(t)$	Inventory during the interval (0, $T_1$ )
$I_2(t)$	Inventory during the interval ( $T_1, T_2$ )
$I_3(t)$	Inventory during the interval ( $T_2, T$ )
$P$	production rate in units per unit time

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$D$	demand rate in units per unit time
$X$	Demand during shortage period per unit per unit time
$Q$	production quantity
$Q_i$	on hand inventory level during $[0, T_1]$
$Q^*$	optimal production quantity
$\tilde{\gamma}$	Production cost per unit per unit time
$h(t)$	holding cost per unit per unit time
$\tilde{h}(t)$	Fuzzy holding cost per unit per unit time
$\tilde{A}$	Fuzzy Setup cost per unit per unit time
$p_i$	Proportion of cost of the machine $m_i$ , $i=1,2,\dots,n$ .
$c_i$	Cost of the machine $m_i$ , $i=1,2,\dots,n$ .
$f_i$	Maintenance cost of the machine $m_i$ , $i=1,2,\dots,n$
$\theta$	Deterioration rate
$u$	Inflation rate
$\tilde{\mu}$	Fuzzy deterioration cost per unit per unit time
$M_i$	Volume of investment in marketing method $i=1,2,\dots,k$ per unit per unit time
$\tilde{L}$	Fuzzy Labour cost for packing per parcel
$\tilde{K}$	Fuzzy Cost of material used for packing per packing
$\tilde{s}$	Fuzzy Shortage cost per unit per unit time
$\pi$	Opportunity cost per unit per unit time
$r$	Number of parcels
$\tilde{TC}$	Fuzzy Total cost
$\tilde{TC}^*$	Fuzzy Optimal total cost
$TC_{DG}$	Defuzzified value of the total cost

## 4.2 ASSUMPTIONS

The following assumptions are made throughout the manuscript:

1. Items are produced and added to the inventory.
2. Shortages are allowed. During the shortage period, the backlogging rate is variable and is dependent on the length of the waiting time for the next replenishment. The longer the waiting time is, the smaller the backlogging rate would be. Hence, the proportion of customers who would like to accept backlogging at time  $t$  is decreasing with the waiting time  $T - t$  waiting for the next replenishment. To take care of this situation we have defined the backlogging rate to be  $\frac{1}{1 + \delta(T - t)}$  when inventory is negative. The backlogging parameter  $\delta$  is a positive constant,  $T_2 \leq t \leq T$ .
3. Production rate is proportional to demand rate.
4. Constant deterioration rate where  $0 < \theta < 1$  and the deteriorated items during the production time are deleted from the inventory.
5. Inflation is also taken in this model.
6. The inventory holding cost is the linear function of time  $h(t) = \alpha + t\beta$  where  $\alpha > 0, \beta > 0$ .
7. The demand rate is stock and time dependent.  $D(t) = a + bI(t) + ct$  where  $a > 0, b > 0, c > 0$ .
8. The packing cost per parcel includes the labour cost and material cost used for packaging.
9. There is no replacement or repair of deteriorated items during the cycle.

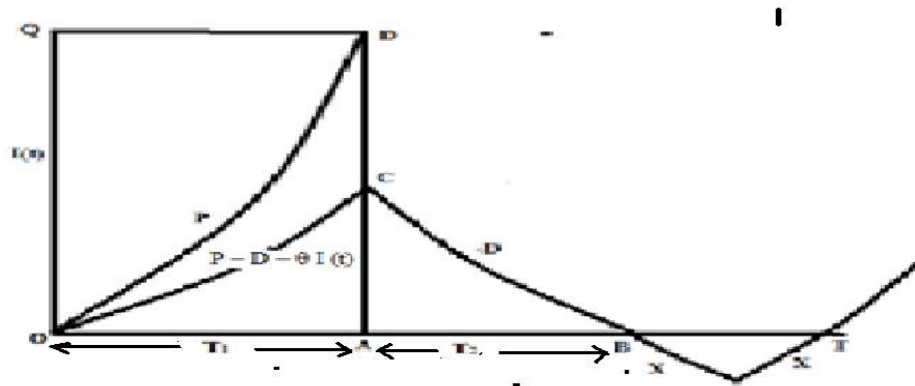
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## V. MODEL DEVELOPMENT

Initially, the stock level is zero. The production starts with at time  $t = 0$  and reaches to maximum inventory level at  $t = T_1$ , production rate is  $P$  and demand rate is  $D$ . Inventory reduces due to demand and deterioration in between  $t = 0$  to  $t = T_1$  the inventory accumulates at the rate of  $P - D - \theta I(t)$ . The production is stopped at  $t = T_1$  and consumption starts from  $t = T_1$  and the stock level is allowed to reduce gradually due to demand and finished at  $t = T_2$ . During the time interval  $[T_2, T]$  all the backlogged shortages are cleared in addition to the fulfilment on hand demand and the cycle repeats thereafter.



The mathematical formulation of the model between  $[0, T]$  is given by

$$\frac{dI(t)}{dt} = \begin{cases} P - D - \theta I(t), & 0 \leq t \leq T_1 \\ -D, & T_1 \leq t \leq T_2 \\ -X, & T_2 \leq t \leq T \end{cases} \quad \text{-----(1) With the boundary}$$

conditions  $I(0) = 0, I(T_1) = Q_1, I(T_2) = 0, I(T) = 0$ .

Here  $D = D(t) = a + bI(t) + ct, h(t) = \alpha + \beta t, 0 < \alpha < 1, \beta > 0, P = \lambda D$  and  $\lambda > 1$

Solutions of equation (1) are

$$I_1(t) = \frac{(\lambda - 1)a}{(\lambda - 1)b - \theta} [e^{((\lambda - 1) - \theta)t} - 1] + \frac{(\lambda - 1)ct}{((\lambda - 1)b - \theta)} + \frac{c(\lambda - 1)}{((\lambda - 1)b - \theta)^2} [e^{((\lambda - 1) - \theta)t} - 1] \quad \text{-----(2)}$$

$$I_2(t) = [e^{b(T_2 - t)} - 1] \left( \frac{a}{b} - \frac{c}{b^2} \right) + \frac{c}{b} [T_2 e^{b(T_2 - t)} - t] \quad \text{-----(3)}$$

$$I_3(t) = X(T - t) \quad \text{-----(4) The total cost is}$$

calculated by considering setup cost, production cost, inventory holding cost, Depreciation cost, opportunity cost, Maintaining cost, Marketing cost, deterioration cost, packaging cost and shortage cost.

### 5.1 The Depreciation cost per cycle

Suppose that the manufacturers owns machine  $m_i (i=1, \dots, n)$  to execute sequentially the various tasks involved in the production process. It is quite natural for the machine to get degraded due to continuous wear and tear, so the value of the machines gets depreciated. The proportion ( $p_i$ ) of costs of machine  $m_i (i=1, \dots, n)$  depreciated is determined by various methods and it varies from one machine to another.

The depreciated cost per cycle is  $= \sum_{i=1}^n p_i C_i$

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### 5.2 The Maintenance cost per cycle

To maintain the degree of reliability and to prevent machine break down the machine have to be properly taken care. Since each machine serves different purposes the pattern of its maintenance also differs.

The maintenance per cycle is  $= \sum_{i=1}^n f_i$

### 5.3 The Marketing cost per cycle

To propagate the product in the market rapidly the manufacturers may prefer one or more marketing strategies, (i.e) for example the manufacturer may advertise his products via two modes viz. Newspaper and Television for which separate cost are incurred.

The marketing cost per cycle is  $= \sum_{i=1}^k M_i$

### 5.4 Packaging cost

Packing cost per parcel includes both the labour costs and the material costs.

Packaging cost per cycle  $= (\tilde{L} + \tilde{K}) r$

### 5.5 Setup cost

$$S\tilde{C} = \frac{\tilde{A}}{T}$$

### 5.6 Production cost

$$\tilde{P}C = \frac{\tilde{\gamma}Q}{T}$$

### 5.7 Inventory holding cost

$$\tilde{H}C = \frac{1}{T} \left[ \left( \alpha\lambda a - \frac{\alpha c}{b} \right) \frac{T_1^2}{2} + \left( a\alpha - \frac{2c\alpha}{b} + \frac{\alpha c}{b} \right) \frac{T_2^2}{2} + \left( \frac{c\alpha}{b} - a\alpha \right) T_1 T_2 \right]$$

### 5.8 Shortage cost

$$\tilde{S}\tilde{H}C = \frac{\tilde{s}}{T} \int_{T_2}^T X(T-t)dt = \frac{\tilde{s}X}{T} \left\{ \frac{T^2}{2} - TT_2 + \frac{T_2^2}{2} \right\}$$

### 5.9 Deterioration cost

$$\begin{aligned} D\tilde{T}C &= \frac{\tilde{\mu}\theta}{T} \int_0^{T_1} I_1(t)dt \\ &= \frac{\tilde{\mu}\theta(\lambda-1)\alpha T_1^2}{2T} \end{aligned}$$

### 5.10. Opportunity cost

$$\begin{aligned} OC &= \frac{\pi}{T} \int_{T_2}^T \left( X - \frac{X}{1+\delta(T-t)} \right) dt \\ &= \frac{\pi}{T} \left[ (X-1)T - (X-1)T_2 + \frac{\delta(T-T_2)^2}{2} \right] \end{aligned}$$

Total cost  $T\tilde{C} = S\tilde{C} + P\tilde{C} + H\tilde{C} + SH\tilde{C} + OC + D\tilde{T}C$  + Depreciation cost +  
Maintenance cost + Marketing cost + Packaging cost

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$$TC_{\tilde{}}(T, T_1) = \frac{1}{T} \left[ \tilde{A} + \tilde{\gamma}Q + \left[ \left( \alpha\lambda a - \frac{\alpha c}{b} \right) \frac{T_1^2}{2} + \left( a\alpha - \frac{2c\alpha}{b} + \frac{\alpha c}{b} \right) \frac{T_2^2}{2} + \left( \frac{c\alpha}{b} - a\alpha \right) T_1 T_2 \right] + \tilde{s}X \left\{ \frac{T^2}{2} - TT_2 + \frac{T_2^2}{2} \right\} + \frac{\tilde{\mu}\theta(\lambda-1)aT_1^2}{2} + \pi \left[ (X-1)T - (X-1)T_2 + \frac{\delta(T-T_2)^2}{2} \right] + \sum_{i=1}^n p_i c_i + \sum_{i=1}^n f_i + \sum_{i=1}^k M_i + (\tilde{L} + \tilde{K})r \right]$$

### 5.10 Defuzzification of the Total cost

$$\tilde{A} = (A_1, A_2, A_3), \tilde{h} = (h_1, h_2, h_3), \tilde{s} = (s_1, s_2, s_3), \tilde{\alpha} = (\alpha_1, \alpha_2, \alpha_3), \tilde{L} = (L_1, L_2, L_3), \tilde{K} = (K_1, K_2, K_3), \tilde{\gamma} = (\gamma_1, \gamma_2, \gamma_3)$$

$$TC_{DG}(T, T_1) = \frac{1}{T} \left[ A + \gamma Q + \left[ \left( \alpha\lambda a - \frac{\alpha c}{b} \right) \frac{T_1^2}{2} + \left( a\alpha - \frac{2c\alpha}{b} + \frac{\alpha c}{b} \right) \frac{T_2^2}{2} + \left( \frac{c\alpha}{b} - a\alpha \right) T_1 T_2 \right] + sX \left\{ \frac{T^2}{2} - TT_2 + \frac{T_2^2}{2} \right\} + \frac{\mu\theta(\lambda-1)aT_1^2}{2} + \pi \left[ (X-1)T - (X-1)T_2 + \frac{\delta(T-T_2)^2}{2} \right] + \sum_{i=1}^n p_i c_i + \sum_{i=1}^n f_i + \sum_{i=1}^k M_i + (\tilde{L} + \tilde{K})r \right]$$

### 5.11 Optimal solution

The necessary condition for the total cost per time unit to minimize is

$$\frac{\partial TC}{\partial T_1} = 0 \text{ and } \frac{\partial TC}{\partial T} = 0$$

$$\text{Provided } \left( \frac{\partial^2 TC}{\partial T_1} \right) \left( \frac{\partial^2 TC}{\partial T^2} \right) - \left( \frac{\partial^2 TC}{\partial T_1 \partial T} \right)^2 > 0 \text{ and } \left( \frac{\partial^2 TC}{\partial T_1^2} \right) > 0$$

The convexity of the function shown graphically in the next section.

## VI. NUMERICAL ILLUSTRATIONS

**Example1:** Consider an inventory system with the following parametric values in proper units:  $n = 3, k = 3, C_1 = 10000, C_2 = 15000, C_3 = 20000, p_1 = 0.5\%, p_2 = 0.3\%, p_3 = 1\%, f_1 = 50/\text{unit}/\text{unit time}, f_2 = 20/\text{unit}/\text{unit time}, f_3 = 10/\text{unit}/\text{unit time}, M_1 = 50/\text{unit}/\text{unit time}, M_2 = 40/\text{unit}/\text{unit time}, \tilde{A} = (90, 100, 110), \tilde{h} = (1, 1.5, 2), \tilde{\gamma} = (50, 60, 70), a = 250, b = 0.2, c = 0.08, \tilde{L} = (1, 2, 3), \tilde{K} = (0.5, 0.6, 0.8), \lambda = 0.8, \tilde{s} = (30, 40, 50), X = 60, \theta = 0.56, r = 1, \alpha = 1.175, \beta = 1, \delta = 0.56, \mu = 1.175$ . The output of the program by using maple mathematical software is  $T=0.7061, T_1=0.8696, T_2=1.1826, TC=1655.274$ .

## VII. SENSITIVITY ANALYSIS

Sensitivity analysis is carried out with the variation of different parameters. Taking all the numerical values as mentioned in the above numerical example.

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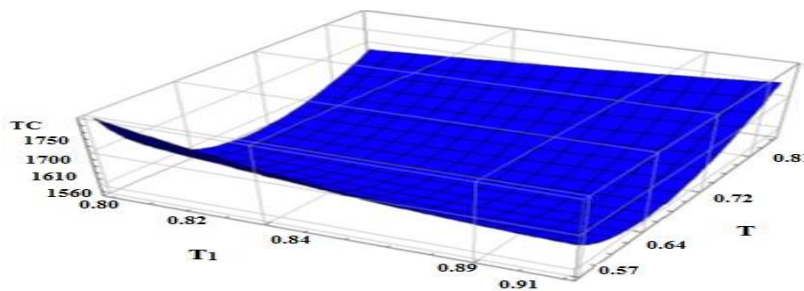
**Table-1 Effect of changes in the parameter of the inventory model**

Parameter	% Change	T	T <sub>1</sub>	TC
A	+40%	0.8187	0.9109	1733.97
	+20%	0.7645	0.8910	1696.07
	-20%	0.6424	0.8462	1610.78
	-40%	0.5716	0.8202	1561.36
$\gamma$	+40%	0.7756	0.8951	1703.87
	+20%	0.7417	0.8827	1680.14
	-20%	0.6686	0.8558	1629.09
	-40%	0.6289	0.8413	1601.34
h	+40%	0.7061	0.8696	1655.27
	+20%	0.7061	0.8696	1655.27
	-20%	0.7061	0.8696	1655.27
	-40%	0.7061	0.8696	1655.27

All the above observations can be sum up as follows:

- Increase in setup cost leads increase in total cost and decrease in setup cost leads decrease in total cost.
- Increase in production cost leads increase in total cost and decrease in production cost leads decrease in total cost.
- Increase in holding cost leads slight increase in total cost and decrease in holding cost leads decrease in total cost.

**Fig.1 Total cost Vs T<sub>1</sub> and T**



## VIII. CONCLUSIONS

As almost all items undergo either direct spoilage or physical decay in the course time i.e. deterioration is natural feature in the inventory system that's why the deterioration factor taken into consideration in the present model with some realistic assumptions like time and stock dependent demand and time dependent holding cost and given analytical solution of the model that minimize the total cost. This model is very practical for the industries. The sensitivity of the model has checked with respect to the various parameter of the system.

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