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Research paper

An EOQ Model for Deteriorating Items with Selling Price Dependent Exponential Demand for Time Varying Holding and Deterioration Costs

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Abstract

Research investigation of the past few decades shown that the researchers developed economic order quantity (EOQ) model for perishable items under constant deterioration and constant demand. Though, in actual practice it is not true. This paper involved a representation of an inventory control model, in which perishable items has been taken with a price as well as an exponential dependent demand. The measured items in the model are deteriorating in nature based on time dependent deterioration rate. In the earlier studies the holding cost often treated as a constant, which is not suited to the most of the practical life situations. In real practical situation some kind of items treat holding cost is a function of time, which is increase as the time increases. In this paper, a model is developed which included the time dependent linear holding cost. We have achieved the estimated optimal solution under the given assumption according to the situation. A numerical example is presented to demonstrate the model and the sensitivity analysis of various parameters is approved out for the validation of the proposed method.

Keywords: *Deteriorating items, price and time dependent demand, shortages and time varying holding cost, Lead time.*

1. Introduction

In different business, Inventory shows a very crucial part in the manufacturing and service organization. For the stable running of the business, every company must carry some inventory. No organization claims that they are not keeping any inventory. Wilson [29], developed a one of the well-known Economic Order quantity model and in the connection of this model a lot of work has been done in the research area. Demand rate is assumed to be a constant in the classical inventory models. But in many everyday situation behavior of demand under different cases shows time, stock, and price dependent selling price has been the cause of demand increment and demand decrement in the inventory system. Sharma, A. et.al [22] [23] focused on the different demand rate for different time interval. Economical quantity lot size model, in which price-dependent demand under quantity and merchandise discounts developed by Burwell [2], which is followed by Mondal, et. al [12]. Mishra, V.K. et.al, [14] [15] and Acharya, M.S.D. [1], Introduced an inventory model for perishable items, in which time dependency demand discussed. Roy, A., [21] and K, Geetha et.al, [10] introduced the model for decaying item in which Roy and Geetha focused on price dependent demand rate function. You [28] and Duari, N.K. [19] explained an inventory model in which the system includes the enriching items for price dependent demand.
Last few decades have been the evidence the study of perishable items has gained enormous importance. In present time the wastage of any kind of natural or unnatural resources is considered as an unavoidable wickedness. Even most of the organizations are facing very tough competition and deterioration of resources would shrink their profit margins considerably. Consequently, in most of the present models the items considered are deteriorating in nature and inventory cost compromises of the deterioration cost. Initially Ghare and Schrader were the first to use the concept of deterioration, they established an inventory model in which constant rate of deterioration has been focused. Ghare and Schrader [9], followed by Covert, and G. C. Philip [4] who formulated a model considering a variable rate of deterioration with two parameter Weibull distribution. Pal, S. [20] further extended the concept of a deteriorating item in his own views and explanation. Nahmais [17] provided the well-defined literature on the various problem of determining suitable ordering policies subject to continuous exponential decay. Singh, C and Singh, S.R [25][26] investigated the model in which exponential demand rate functions well as the weibull distribution of deterioration rate is used Many authors explained the Lead time related research .This topic has been the interest of many researchers. Lead time is recommended in deterministic as well as probabilistic cases. Assumed by Ben-day [3], Das [6], Foote [7], Magson [11], Naddor [18], Chung, and Ting, [5], Fujiwara [17]. Singh, S.R [27] touch the issue of lead time in his own research area and developed a supply chain model for inventory system though, in many practical situations lead time can be reduced at an added cost. By reducing the lead time, customer service and reaction to production schedule changes can be improved and reduction in safety stocks can be achieved. Singh, C. [24] developed an inventory control model and focused on problem of shortage in daily life situation.
In this paper, we extended the idea of M. Maragatham and R. Palani [16], an inventory model for deteriorating items with lead time price dependent demand and shortages.

2. Notations and Assumptions

Notations

The following notations are used in developing the model.

DA : Amount of material deterioration during a cycle time.
DR (t) : Time dependent Deterioration rate.
D $(p$, t$)$: Demand rate
t_1 : Replenishment cycle time.
k : Lead time.
PC : Purchase cost.
SC : Shortage cost.
HC : The total cost of holding inventory per cycle.
DC : Total deterioration cost per cycle.
Q : Maximum Inventory Level.
C_h : The inventory holding cost per unit item per unit time.
C_d : The inventory deteriorating cost per unit item per unit time
C_s : The inventory shortage cost per unit item per unit time
C_P : The inventory purchasing cost per unit item per unit time.
C_o : The inventory ordering cost per unit item per unit time.
I1(t) : The inventory level at time ($0 \le t \le k$).
I2(t) : The inventory level at time ($t_1 \le t \le T$).

Assumptions

We have assumed the following assumptions for the model.

i. The demand rate *D (p, t)* is price & exponential time depending and is of the form $D(p,t) = me^{nt} + ap^{-b}$, $b > 0$, p is selling price.
ii. The item cost remains constant irrespective of the order size.
iii. Shortages are allowed to occur.
iv. Replenishment rate is infinite and the lead time is constant.
v. Holding cost is a function of time.
vi. Deterioration is not instantaneous.
vii. The rate of deterioration at any time $t > 0$ follow the two parameter Weibull distribution as $\theta = \alpha\beta t^{(\beta-1)}$, Where *α (0<α<1)* and *β (<0)* are the scale and shape parameter.
viii. Replenishment not allowed for the deteriorated items throughout the cycle.
ix. The inventory is refilled only once throughout each cycle.
x. During lead time shortages are allowed
xi. Ordering quantity is *q + D (p, t)* when *t=k.*

3. Mathematical Model and Analysis

In this model deterministic demand is assumed which is a function of price as well as time and running down on the inventory take place due to demand and deterioration in each cycle. The objective of this model is to conclude the optimal order amount and the length of the assembling cycle so as to keep the total significant cost as low as possible, where the holding cost is a function time and shortage are allowed. The inventory level at t=0 is zero. After t=k time interval inventory level is which is reduced to zero at the time t= t_1.Now shortage occur and mount up to the level w_1, at t = T. The behavior of the inventory system at any time is shown in fig 1.

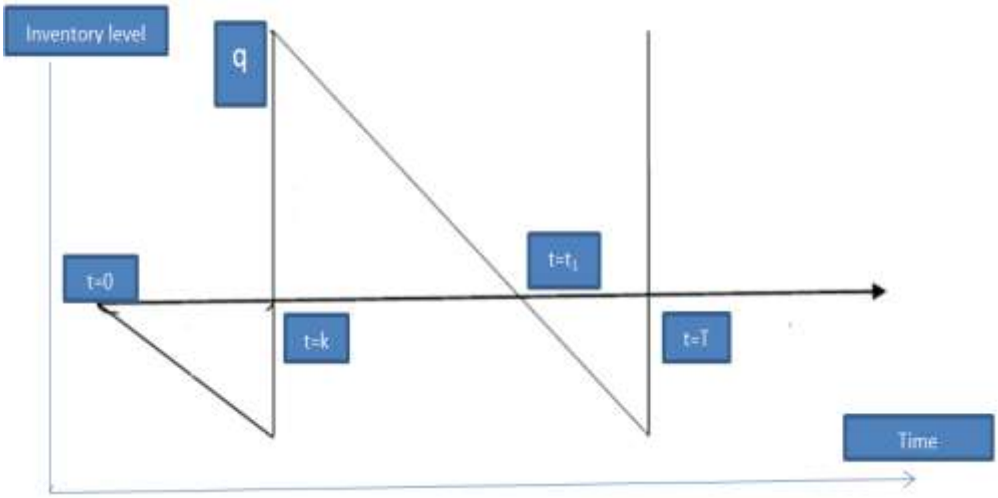

Fig. 1: Graphical representation of the inventory system

State of the $I_1(t)$ and $I_2(t)$ are the inventory level during cycle time T is given by the following differential equations

$$\frac{dI_1(t)}{dx} + \alpha\beta t^{\beta-1} I(t) = -(ap^{-b} + me^{nt}), \; k \le t \le t_1 \tag{1}$$

$$\frac{dI_2(t)}{dx} = -ap^{-b} \qquad , t_1 \le t \le T \tag{2}$$

Solution of **(1)** with the boundary value condition, $I_1(t_1) = 0$

$$I_1(t) = \begin{Bmatrix} (m + ap^{-b})(t_1 - t) + \frac{mn}{2}(t_1^2 - t^2) \\ -\left(\frac{m\alpha}{\beta+1} + \frac{\alpha a p^{-b}}{\beta+1}\right)(t_1^{\beta+1} - t^{\beta+1}) \end{Bmatrix} (1 - \alpha t^{\beta}) \tag{3}$$

at, $t = k$, $I_1 = q$, i.e $I_1(k) = q$

$$q = \begin{Bmatrix} (m + ap^{-b})(t_1 - k) + \frac{mn}{2}(t_1^2 - k^2) \\ -\left(\frac{m\alpha}{\beta+1} + \frac{\alpha a p^{-b}}{\beta+1}\right)(t_1^{\beta+1} - k^{\beta+1}) \end{Bmatrix} (1 - \alpha t^{\beta}) \tag{4}$$

Solution of **(2)** with the boundary value condition, $I_2(T) = -w_1$

$$I_2(t) = m(t_1 - T)(m + ap^{-b}) + \frac{n}{2}(t_1^2 - T^2) \tag{5}$$

The total variable cost will comprise the following components costs.

(a). The ordering cost (OC) of the materials, which is fixed per order for the present financial year, is given by

$$OC = C_o \tag{6}$$

(b). The Deterioration cost (DC) is given by

DC $= C_d \times$ DA (Amount of material deterioration during a cycle time)

=

$$C_d\left\{(m + ap^{-b})(t_1 - k) + \frac{mn}{2}(t_1^2 - k^2) - m(t_1 - t) + \frac{mn}{2}(t_1^2 - k^2) + ap^{-b}(t_1 - k)\right\} \tag{7}$$

(c). Holding cost (HC) is given by the below equation

$$HC = C_h \int_k^{t_1} I_1(t)dt = C_h$$

$$\Big[(m + ap^{-b})(t_1^2 - \frac{t_1^2}{2} - t_1 k + \frac{k}{2}) + \frac{mn}{2}(t_1^3 - \frac{t_1^3}{3} - t_1^2 k + \frac{k^3}{3}$$
$$+ (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+2} - \frac{t_1^{\beta+2}}{\beta+2} - t_1^{\beta+1}k + \frac{k^{\beta+2}}{\beta+2})$$
$$+ (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+2} - \frac{t_1^{\beta+2}}{\beta+2} - t_1^{\beta+1}k + \frac{k^{\beta+2}}{\beta+2})$$
$$- (m\alpha + a\alpha p^{-b})(\frac{t_1^{\beta+2}}{\beta+1} - \frac{t_1^{\beta+2}}{\beta+2} - \frac{t_1 k^{\beta+2}}{\beta+1} + \frac{k^{\beta+2}}{\beta+2})$$
$$- \frac{mn}{2}(\frac{t_1^{2\beta+2}}{\beta+1} - \frac{t_1^{\beta+2}}{\beta+2} - \frac{t_1 k^{\beta+1}}{\beta+1}k^{\beta+1} + \frac{k^{\beta+2}}{\beta+2}\Big] \tag{8}$$

The purchasing cost (PC) is given by

$$PC = C_p[q - k\,D(p,t)]$$

$$= C_p\left\{\begin{array}{l}(m+ap^{-b})(t_1 - k) + \frac{mn}{2}(t_1^2 - k^2) \\ - (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+1} - k^{\beta+1})\}(1-\alpha k^{\beta}) \\ - k\,(ap^{-b} + me^{nt})\end{array}\right\} \tag{9}$$

(e).The shortage cost (SC) is given by

$$SC = -C_s \int_{t_1}^{T} I_2(t)dt = -C_s\left\{\begin{array}{l}(m\alpha + a\alpha p^{-b})(2t_1 k - T^2 t_1^2) \\ + \frac{n}{2}(t_1^2 T - T^2 t_1 - T^3 - t_1^3)\end{array}\right\} \tag{10}$$

Total variable cost function for one cycle is given by

TC = (Ordering cost + purchasing cost + holding cost + deteriorating cost + Shortage cost)

$TC = OC + PC + HC + DC + SC$

Total Average Cost (TAC) is given by

$$TAC = \frac{1}{T}(OC + PC + HC + SC + DC)$$

$$= \frac{1}{T}[C_o + C_d\left\{\begin{array}{l}(m + ap^{-b})(t_1 - k) + \frac{mn}{2}(t_1^2 - k^2) \\ - m(t_1 - t) + \frac{mn}{2}(t_1^2 - k^2) + ap^{-b}(t_1 - k)\end{array}\right\}$$

$$+C_h\left\{\begin{array}{l}(m + ap^{-b})(t_1^2 - \frac{t_1^2}{2} - t_1 k + \frac{k}{2}) + \frac{mn}{2}(t_1^3 - \frac{t_1^3}{3} - t_1^2 k + \frac{k^3}{3} + (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+2} - \frac{t_1^{\beta+2}}{\beta+2} - t_1^{\beta+1}k + \frac{k^{\beta+2}}{\beta+2}) \\ + (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+2} - \frac{t_1^{\beta+2}}{\beta+2} - t_1^{\beta+1}k + \frac{k^{\beta+2}}{\beta+2}) - (m\alpha + a\alpha p^{-b})(\frac{t_1^{\beta+2}}{\beta+1} - \frac{t_1^{\beta+2}}{\beta+2} - \frac{t_1 k^{\beta+2}}{\beta+1} + \frac{k^{\beta+2}}{\beta+2}) \\ - \frac{mn}{2}(\frac{t_1^{2\beta+2}}{\beta+1} - \frac{t_1^{\beta+2}}{\beta+2} - \frac{t_1 k^{\beta+1}}{\beta+1}k^{\beta+1} + \frac{k^{\beta+2}}{\beta+2})\end{array}\right\}$$

$$+C_p\left\{\begin{array}{l}(m+ap^{-b})(t_1 - k) + \frac{mn}{2}(t_1^2 - k^2) - (\frac{m\alpha}{\beta+1} + \frac{a\alpha p^{-b}}{\beta+1})(t_1^{\beta+1} - k^{\beta+1})\}(1-\alpha k^{\beta}) \\ - k\,(ap^{-b} + me^{nt})\end{array}\right\}$$

$$-C_s\left\{(m\alpha + a\alpha p^{-b})(2t_1 k - T^2 t_1^2) + \frac{n}{2}(t_1^2 T - T^2 t_1 - T^3 - t_1^3)\right\}] \tag{11}$$

Objective of our problem which is assumed in our model is to determine optimum value of t_1, so that the minimize value TAC can be achieved. The values t_1 for which $\frac{\partial(TAC)}{\partial t_1} = 0$ satisfying the condition $\frac{\partial^2(TAC)}{\partial t_1^2} > 0$ .The optimal solution of our problem will be achieved from equation (11) by using Mathematica software. This has been demonstrated by the following numerical example.

4. Numerical Example

We have taken the following parametric values for our model to find optimum value.

$C_o = 300,\ C_d = 0.5,\ C_p = 0.9,\ C_s = 0.7,\ C_h = 0.7,\ \alpha = 0.05,\ \beta = 0.04,\ k =, 0.5,\ T = 10,$

$m = 20;\ n = 0.01;\ a = 60,\ b = 0.04,\ p = 12,\ year,$

We obtain the optimal value of $t^*_1 = 0.271005$ days, and minimum total cost

$TAC^* = 498.246$ / year

5. Sensitive Analysis

Sensitivity analysis between different parameter is shown below.

Table-1: Depicts the Sensitivity Analysis with respect to demand parameter 'C_d'

C_d	t_1*	TAC*
0.3	0.380518	501
0.4	0.3195	499.919
0.5	0.271005	498.346
0.6	0.231853	496.353
0.7	0.1999	494.192

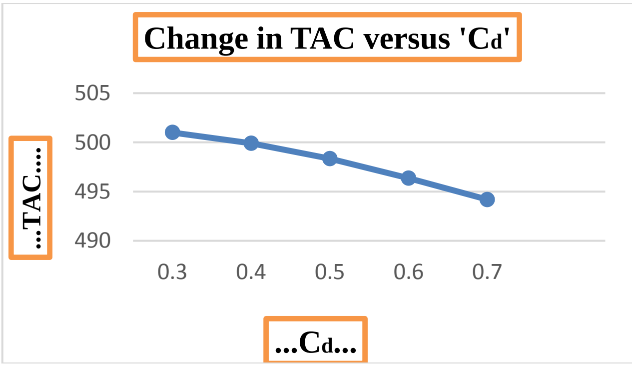

Fig. 2: Changes in T.A.C. versus 'C_d'

Table-2: Depicts the Sensitivity Analysis with respect to demand parameter 'C_h'

C_h	t_1*	TAC*
0.5	0.268855	498.618
0.6	0.269934	498.452
0.7	**0.271005**	**498.286**
0.8	0.272069	498.119
0.9	0.273125	497.952

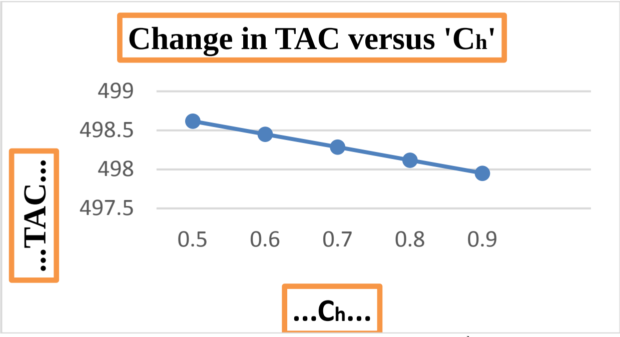

Fig. 3: Changes in T.A.C. versus ‘C^h’

Table-3: Depicts the Sensitivity Analysis with respect to demand parameter‘C_s’

C_s	t_1*	TAC*
0.5	0.118742	355.118
0.6	1.86842	427.257
0.7	**0.271005**	**498.286**
0.8	0.370256	567.987
0.9	0.48315	636.168

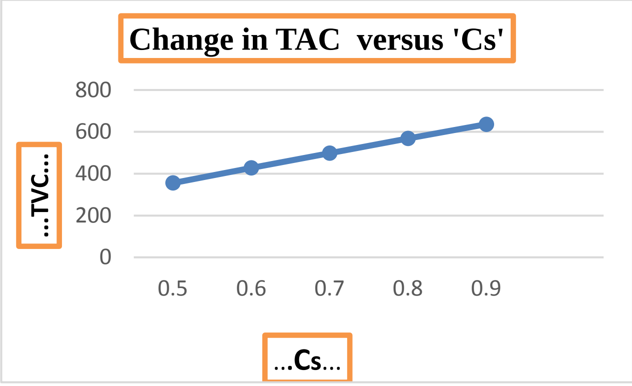

Fig. 4: Changes in T.A.C. versus ‘C_s’

Table-4: Depicts the Sensitivity Analysis with respect to demand parameter‘C_p’

C_p	t_1*	TAC*
0.7	0.3936	500
0.8	0.3251	499.679
0.9	0.2277	496.524
1	0.227795	496.524
1.1	0.192965	494.485

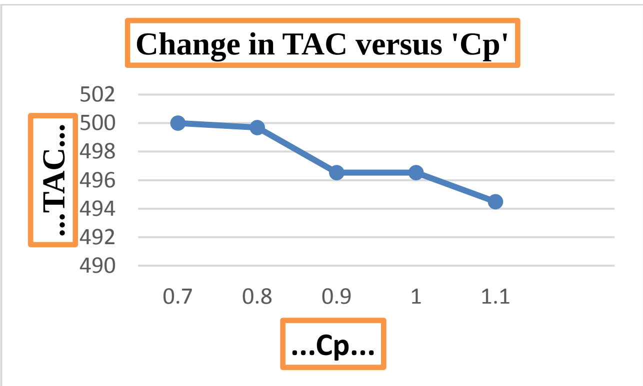

Fig. 5: Changes in T.A.C. versus ‘C_p’

Table-5: Depicts the Sensitivity Analysis with respect to demand parameter ‘‘*a*’

a	t_1*	TAC*
40	0.358532	386.176
50	0.30475	442.343
60	**0.2277**	**496.524**
70	0.24799	554
80	0.231368	609.854

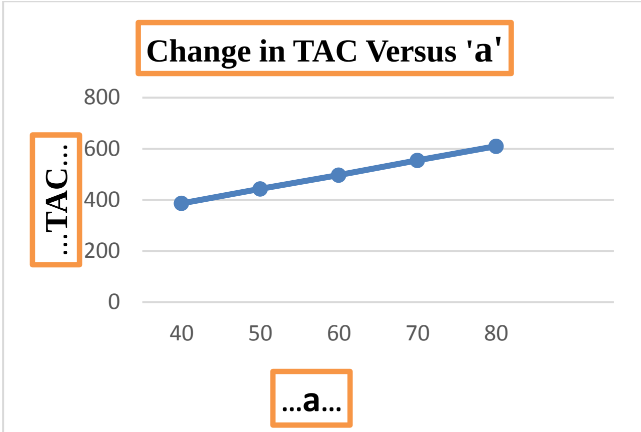

Fig. 6: Changes in T.A.C. versus ‘a’

Table-6: Depicts the Sensitivity Analysis with respect to demand parameter ‘*b*’

b	t_1*	TAC*
0.2	0.294109	516.609
0.3	0.282309	507.344
0.4	**0.2277**	**496.524**
0.5	0.26018	489.431
0.6	0.249814	480.775

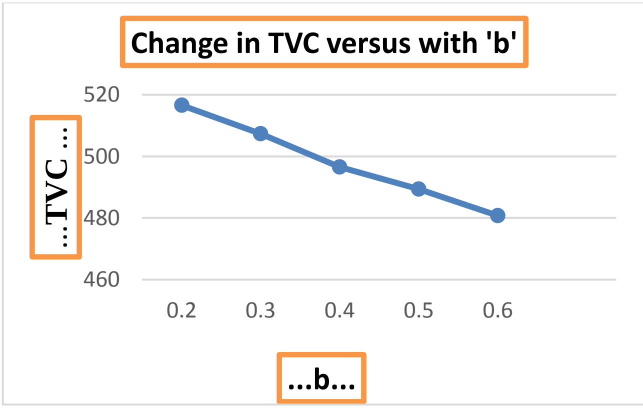

Fig. 7: Changes in T.A.C. versus ‘b’

Table-7: depicts Sensitivity the Analysis with respect to demand parameter ‘*m*’

m	t_1*	TAC*
0	0.30326	179.203
10	0.83615	435.479
20	**0.2277**	**496.524**
30	0.142185	549.656
40	0.093507	598.977

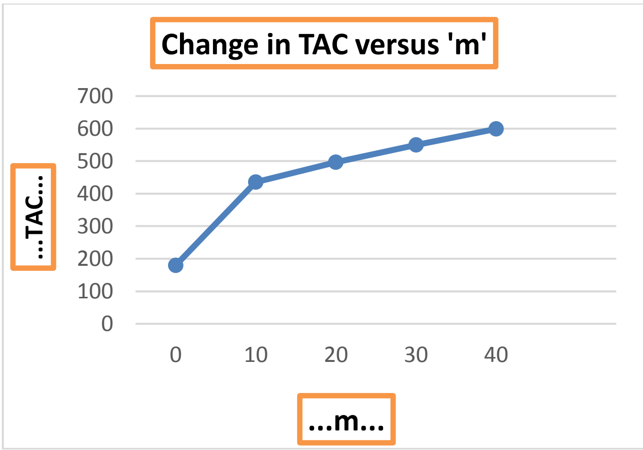

Fig.8: Changes in T.A.C. versus ‘m’

Table8: depicts the Sensitivity Analysis with respect to demand parameter '*n*'

n	t_1*	TAC*
-0.01	0.2712012	497.589
00	0.271104	497.938
0.01	**0.2277**	**496.524**
0.02	0.269079	504.899
0.03	0.268029	508.381

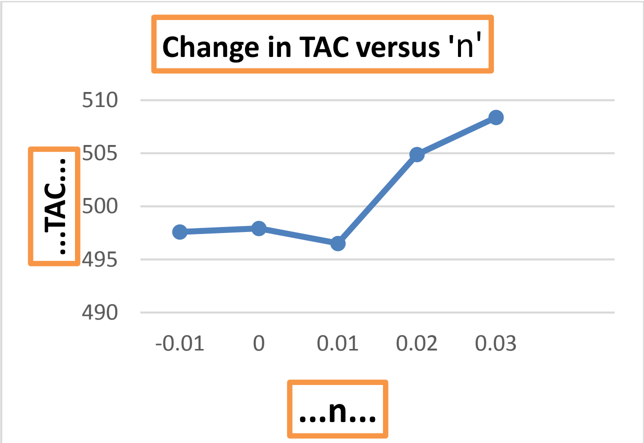

Fig.9: Changes in T.A.C. versus 'n'

Table-9: depicts the Sensitivity Analysis with respect to demand parameter '*p*'

P	t_1*	TAC*
10	0.2644	500.509
11	0.2644	500.509
12	**0.2277**	**498.078**
13	0.259861	496.713
14	0.258594	495.647

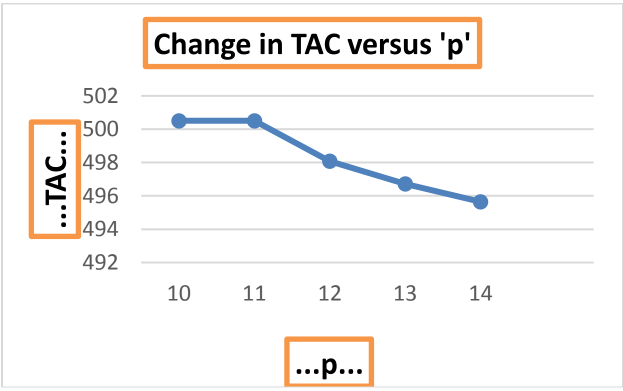

Fig. 10: Changes in T.A.C. versus *'p'*

Table-10: depicts the Sensitivity Analysis with respect to demand parameter '*k*'

k	t_1*	TAC*
0.3	0.252235	521.219
0.4	0.256815	510.121
0.5	**0.2277**	**498.078**
0.6	0.26555	484.601
0.7	0.269812	470.425

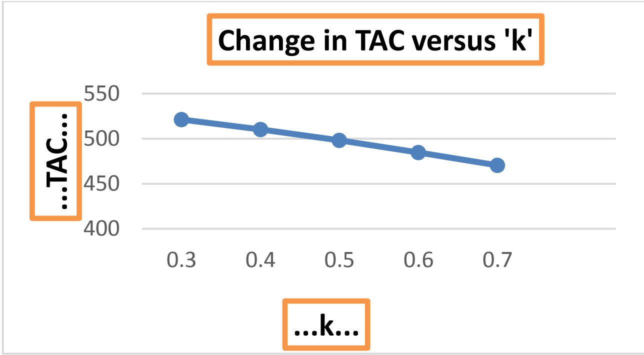

Fig. 11:. Changes in T.A.C. versus 'k'

After observing sensitivity analysis, the results are as follows:

I. With increase/decrease in parameter C_d, t_1* decreases/increases and total cost *TAC** decreases/increases respectively.

II. With increases/decreases in parameterC_h, t_1* increases/decreases and total cost *TAC** decreases/increases respectively.

III. With increases/decreases in parameterC_s, t_1* increases/decreases and total cost *TAC** increases/decreases respectively.

IV. With increase/decreases in parameter C_p, t_1* decreases/increases and total cost *TAC** decreases/increases respectively.

V. With increase/decreases in demand parameter *a*, t_1* decreases/increases and total cost *TAC** increases/decreases respectively.

VI. With increase/decreases in demand parameter *b*, t_1* decreases/increases and total cost *TAC** decreases/increases respectively.

VII. With increase/decreases in demand parameter *m*, t_1* decreases/increases and total cost *TAC** increases/decreases respectively.

VIII. With increases/decreases in demand parameter *p*, t_1* decreases/increases and total cost *TAC** decreases/increases respectively

IX. With increases/decreases in demand parameter *n*, t_1* decreases/increases and total cost *TAC** increases/decreases respectively.

X. With increases/decreases in demand parameter *k*, t_1* increases/decreases and total cost *TAC** decreases/increases respectively.

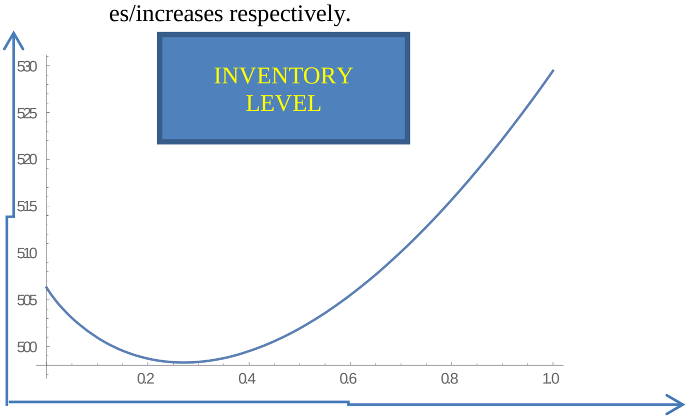

Fig. 12: Relation between t^* and TAC*

6. Conclusion

In this paper, We have introduced deterministic inventory model for deteriorating items in single warehouse and consider the lead time as constant. The demand rate is assumed to be a function of selling price and time dependent exponential function. Shortages are permissible throughout the lead time and entirely backlogged in the present model. Consideration of shortages is economically desirable in these cases; deterioration is a natural future in inventory system. In future researchers can do more work about several types of demand variable costs etc.

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