"EOQ Model For Deteriorating Items Under Two And Three Parameter Weibull Distribution And Constant IHC With Partially Backlogged Shortages"

DEVYANI CHATTERJI, U. B. GOTHI

Abstract– In this paper, we have analysed an inventory model for deteriorating items with constant holding cost. Two and three parameter Weibull distributions are assumed for time to deterioration of items for two different time intervals. Shortages are allowed to occur and they are partially backlogged. The derived model is illustrated by a numerical example and its sensitivity analysis is carried out.

Keywords– Deterioration, Shortages, Weibull distribution, Constant holding cost

I. INTRODUCTION

Many researchers have developed inventory models to maximize the profit (or) to minimize the total cost for deteriorating items with respect to time. Deterioration arises due to some changes in the product which makes the product value dull. Deterioration in each product cannot be completely avoided and the rate of deterioration for each product will vary.

Hill [10] resolved the indiscipline of time dependent demand pattern by considering the demand as the combination of two different types of disciplined demand in two successive time periods over the entire time horizon and termed it as ramp – type time dependent demand pattern. The characteristic of ramp – type demand can be found in Mandal and Pal [12]. Order level inventory system with ramp–type demand rate has been taken for deterioration items. Wu [19](2001) further investigated the inventory model with ramp type demand rate such that the deterioration followed the

Weibull distribution. However, he did not guarantee the existence and uniqueness of the solution. Giri et al. [7] noted a demand pattern for fashionable products which increases exponentially with time for the seasonal products the steady rather than increasing exponentially. But for fashionable products as well as for the seasonal products the steady demand after its exponential increment with time never is continued indefinitely. Rather it would be followed by exponential decrement with respect to time after a period of time and becomes asymptotic in nature.

Gothi U. B. and Chatterji [8] have developed an inventory model for imperfect quality items under constant demand rate and varying inventory holding cost. Further Parmar and Gothi U. B. [14] have developed an inventory model for deteriorating items under quadratic demand with time dependent inventory holding cost. Wu et al. 1999 [20] developed an *EOQ* model with ramp type demand rate for items with Weibull deterioration. Many researches have been done on this subject. Wu and Ouyang 2000 [21] extended the inventory model to include two different replenishment policies: (a) model started with no shortages and (b) model starting with shortages. Kirtan Parmar, Indu Aggarwal and Gothi U. B. [13] have formulated an order level inventory model for deteriorating items under varying demand condition. AzizulBaten and Abdulbadsah [2] developed an inventory model in which the shortages are not

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allowed with constant demand and deterioration rate. Many researchers were interested in taking Weibull deteriorating rate. Gothi U.B. and Parmar [9] developed an order level lot size inventory model for deteriorating items under quadratic demand with time dependent IHC and partial backlogging.

Tripathy and Mishra [16] developed a time dependent demand rate with shortages which are completely backlogged. Tripathy and Pradhan [17] improved their model for not only power demand but also partially backlogged. Kun-Shan Wu [11] presented an ordering policy for items with Weibull deteriorating rate and permissible delay in payments. Covert and Philip [5] presented an inventory model where the time to deterioration is described with two parameter Weibull distribution. Ghosh and Chaudhuri [6] presented an inventory model for Weibull deteriorating items with two parameters, shortages are allowed and demand rate is quadratic. Parmar& Gothi [15] developed an EOQ model of deteriorating items using three parameter Weibull distribution with constant production rate and time varying holding cost. Chandrashekharan and Amutha [1] developed a deteriorating inventory model for two parameter Weibull deterioration with shortages. Chatterji and Gothi U. B. [4] developed an inventory model with Weibully distributed deterioration rate and time varying IHC.

Vashistha [18] developed an inventory model with Weibull distribution deterioration and time dependent demand. Bhojak and Gothi U.B. [3] developed an inventory model with time dependent demand and two parameter Weibull distributed deterioration with partially backlogged shortages. In this paper, we have redeveloped the above models by considering time dependent demand and both two parameter and three parameter Weibully distributed deterioration rates. We have considered two types of deterioration rates because in many situations, whenever a product is launched in the market initially because of the inefficiency of machines or untrained workers number of defective items produced is quite high. Gradually according to the need, the machines are set and the workers also are trained, the deterioration of the produced lot becomes steady in the following time interval. So in the given model during the time interval $\left[0,\mu\right]$ the deterioration rate is taken as $\theta(t)=\alpha\beta t^{\beta-1}$ whereas in the time interval $\left[\mu,t_1\right]$ it is taken as $\theta(t)=\alpha\beta\left(t-\mu\right)^{\beta-1}$ which is less than the previous deterioration rate. Shortages are allowed with partial backlogging. Numerical example and sensitivity analysis are also carried out by changing the values of all the parameters one by one.

II. NOTATIONS

The following notations are used to develop the model:

1. Q(t) : Inventory level of the product at time t $(t \geq 0)$.
2. R(t) : Demand rate varying over time.
3. θ(t) : Deterioration rate.
4. A : Ordering cost per order during The cycle period.
5. C_h : Inventory holding cost per unit per unit time.
6. C_d : Deterioration cost per unit per unit time.
7. C_s : Shortage cost per unit per unit time.
8. l : Unit cost of lost sales.
9. S : Initial inventory level after fulfilling backorders.
10. S_1 : Inventory level at time $t=\mu$.
11. δ : Backlogging parameter which is a small positive constant.
12. T : Length of the replenishment cycle.

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13. TC : The average total cost for the time period [0, T].

III. ASSUMPTIONS

The following assumptions are considered to develop the model:

1. Replenishment rate is infinite and lead time is zero.
2. A single item is considered over the prescribed period of time.
3. No repair or replenishment of the deteriorated items takes place during a given cycle.
4. Demand rate $R(t)$ is assumed to be a function of time such that
   $R(t) = a + bt + c\{t - (t-\mu)H(t-\mu)\}t,$
   Where $H(t-\mu)$ is the Heaviside's function defined as
   $$H(t-\mu) = \begin{cases} 1, & if\ \ t \ge \mu \\ 0, & if\ \ t < \mu \end{cases}$$
   & a is the initial rate of demand, b is the Rate with which the demand rate increases. The rate of change in demand rate itself increases at a rate c. a, b & c are positive constants.
5. $\theta(t) = \alpha\beta t^{\beta-1}$ is the two parameter Weibull deterioration rate in the time interval $[0, \mu]$, where α is scale parameter $(0 < \alpha << 1)$ and β is shape parameter.
6. $\theta(t) = \alpha\beta(t-\mu)^{\beta-1}$ is the three parameter Weibull deterioration rate in the time interval $[\mu, t_1]$, where α is scale parameter $(0 < \alpha << 1)$, β is shape parameter and μ is the location parameter.
7. Shortages are allowed and unsatisfied demand is backlogged at a rate $e^{-\delta(T-t)}$, where the backlogging parameter δ is a positive constant.
8. Total inventory cost is a real and continuous function which is convex to the origin.

IV.MATHEMATICAL MODEL AND ANALYSIS

In case of volatile liquids like petrol, diesel, kerosene etc. deterioration rate depends upon the on hand inventory i.e. when the quantity is large deterioration rate is more and eventually as the quantity decreases deterioration rate also decreases. So in the mathematical model of this paper, deterioration rate $\alpha\beta t^{\beta-1}$ is more in the time interval $[0, \mu]$ than the deterioration rate $\alpha\beta(t-\mu)^{\beta-1}$ in the time interval $[\mu, t_1]$ is taken as $S > S_1$ [S and S_1 are the on hand inventories in the time intervals $[0, \mu]$ and $[\mu, t_1]$ respectively.

The stock level is S at time t=0, then inventory level decreases mainly to meet up demand with demand rate $(a + bt + ct^2)$ and partly due to the deterioration rate $\alpha\beta t^{\beta-1}$ and reaches to S_1 at $t = \mu$. The stock level falls to zero level till time $t = t_1$ due to demand with rate $(a + mt)$ where $m = (b + c\mu)$ along with the deterioration rate $\alpha\beta(t-\mu)^{\beta-1}$. Thereafter, shortages are allowed to occur during the time interval $[t_1, T]$ and demand is partially backlogged during this time interval.

The pictorial presentation is shown in the Figure – 1.

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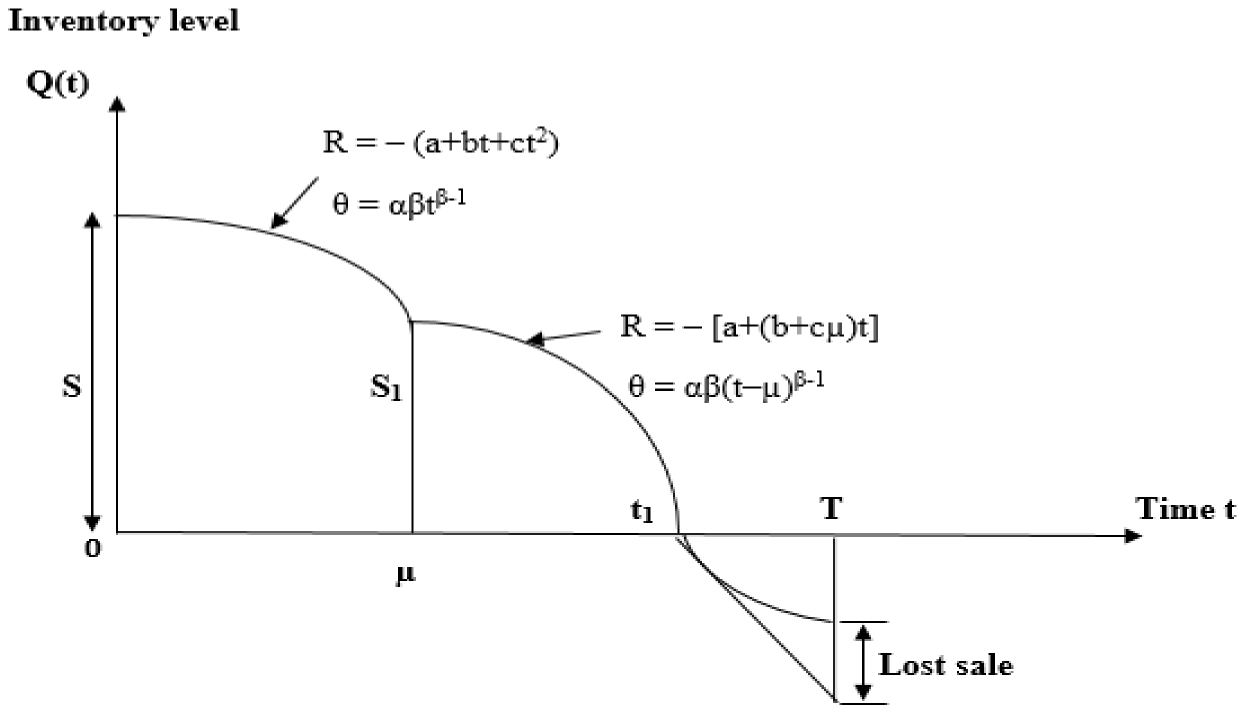

Figure 1: Graphical presentation of the inventory system

The differential equations which governs the instantaneous state of *Q(t)* over the time intervals $(0,\mu),(\mu,t_1)$ *and* (t_1,T) are given by

$$\frac{dQ(t)}{dt}+\alpha\beta t^{\beta-1}Q(t)=-(a+bt+ct^2); \qquad (0\le t\le\mu) \qquad (1)$$

$$\frac{dQ(t)}{dt}+\alpha\beta(t-\mu)^{\beta-1}Q(t)=-[a+(b+c\mu)t]; \qquad (\mu\le t\le t_1) \qquad (2)$$

$$\frac{dQ(t)}{dt}=-[a+(b+c\mu)t]e^{-\delta(T-t)}; \qquad (t_1\le t\le T) \qquad (3)$$

Under the boundary conditions $Q(0)=S,\ Q(\mu)=S_1$ and $Q(t_1)=0$ the solutions of equations (1), (2) and (3) are given by

$$Q(t)=\begin{bmatrix} S(1-\alpha t^{\beta})-\left(at+\frac{bt^2}{2}+\frac{ct^3}{3}\right)+\frac{a\alpha\beta}{\beta+1}t^{\beta+1}+\frac{b\alpha\beta}{2(\beta+2)}t^{\beta+2} \\ +\frac{c\alpha\beta}{3(\beta+3)}t^{\beta+3} \end{bmatrix}; \qquad (0\le t\le\mu) \qquad (4)$$

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$$Q(t)=\begin{bmatrix} S_1\left\{1-\alpha(t-\mu)^{\beta}\right\}-\left(a+m\mu\right)(t-\mu)-\frac{m}{2}(t-\mu)^2 \\ +\frac{\left(a+m\mu\right)\alpha\beta}{\beta+1}(t-\mu)^{\beta+1}+\frac{m\alpha\beta}{2(\beta+2)}(t-\mu)^{\beta+2} \end{bmatrix}; \qquad \left(\mu\le t\le t_1\right) \tag{5}$$

$$Q(t)=a(1-\delta T)(t_1-t)+\frac{m(1-\delta T)+a\delta}{2}(t_1^2-t^2)+\frac{m\delta}{3}(t_1^3-t^3); \qquad (t_1\le t\le T) \tag{6}$$

Putting $Q(\mu) = S_1$ in equation (4), we get

$$S_1=S(1-\alpha\mu^{\beta})-\left(a\mu+\frac{b\mu^2}{2}+\frac{c\mu^3}{3}\right)+\frac{a\alpha\beta}{\beta+1}\mu^{\beta+1}+\frac{b\alpha\beta}{2(\beta+2)}\mu^{\beta+2}+\frac{c\alpha\beta}{3(\beta+3)}\mu^{\beta+3} \tag{7}$$

Putting $Q(t_1) = 0$ in equation (5), we get

$$S_1=\frac{\left[\left(a+m\mu\right)(t_1-\mu)+\frac{m}{2}(t_1-\mu)^2-\frac{\left(a+m\mu\right)\alpha\beta}{\beta+1}(t_1-\mu)^{\beta+1}-\frac{m\alpha\beta}{2(\beta+2)}(t_1-\mu)^{\beta+2}\right]}{1-\alpha\left(t_1-\mu\right)^{\beta}} \tag{8}$$

From equation (7) and (8), we get

$$S=\frac{1}{(1-\alpha\mu^{\beta})}\left\{\begin{matrix} \frac{\left[\left(a+m\mu\right)(t_1-\mu)+\frac{m}{2}(t_1-\mu)^2-\frac{\left(a+m\mu\right)\alpha\beta}{\beta+1}(t_1-\mu)^{\beta+1}-\frac{m\alpha\beta}{2(\beta+2)}(t_1-\mu)^{\beta+2}\right]}{1-\alpha\left(t_1-\mu\right)^{\beta}} \\ +\left(a\mu+\frac{b\mu^2}{2}+\frac{c\mu^3}{3}\right)-\frac{a\alpha\beta}{\beta+1}\mu^{\beta+1}-\frac{b\alpha\beta}{2(\beta+2)}\mu^{\beta+2}-\frac{c\alpha\beta}{3(\beta+3)}\mu^{\beta+3} \end{matrix}\right\} \tag{9}$$

The total cost per unit time comprises of the following costs:

1. Operating Cost

$$OC=A \tag{10}$$

2. Holding Cost

$$IHC=C_h\left[\int_0^{\mu}Q(t)dt+\int_{\mu}^{t_1}Q(t)dt\right]$$

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$$\therefore IHC = C_h \left[\begin{array}{l} \left\{ \begin{array}{l} S\left(\mu - \dfrac{\alpha\mu^{\beta+1}}{\beta+1}\right) - \left(\dfrac{a\mu^2}{2} + \dfrac{b\mu^3}{6} + \dfrac{c\mu^4}{12}\right) + \dfrac{a\alpha\beta\mu^{\beta+2}}{(\beta+1)(\beta+2)} \\ + \dfrac{b\alpha\beta\mu^{\beta+3}}{2(\beta+2)(\beta+3)} + \dfrac{c\alpha\beta\mu^{\beta+4}}{3(\beta+3)(\beta+4)} \end{array} \right\} + \\ \left\{ \begin{array}{l} S_1\left(t_1-\mu\right) - \dfrac{S_1\alpha(t_1-\mu)^{\beta+1}}{\beta+1} - \dfrac{\left(a+m\mu\right)(t_1-\mu)^2}{2} - \dfrac{m(t_1-\mu)^3}{6} \\ + \dfrac{\left(a+m\mu\right)\alpha\beta(t-\mu)^{\beta+2}}{(\beta+1)(\beta+2)} + \dfrac{m\alpha\beta(t_1-\mu)^{\beta+3}}{2(\beta+2)(\beta+3)} \end{array} \right\} \end{array} \right] \quad (11)$$

3. Shortage Cost

$$SC = -C_s \int_{t_1}^{T} Q(t)dt$$

$$\therefore SC = C_s \left[\begin{array}{l} a(1-\delta T)\dfrac{\left(T-t_1\right)^2}{2} + \dfrac{m(1-\delta T)+a\delta}{2}\left\{\dfrac{(T-t_1)^3}{3} + t_1(T-t_1)^2\right\} \\ + \dfrac{m\delta}{3}\left\{\dfrac{(T-t_1)^4}{4} + t_1(T-t_1)^3 + \dfrac{3t_1^2}{2}(T-t_1)^2\right\} \end{array} \right] \quad (12)$$

4. Deterioration Cost

$$DC = C_d \left[\int_0^{\mu} \alpha\beta t^{\beta-1}Q(t)dt + \int_{\mu}^{t_1} \alpha\beta(t-\mu)^{\beta-1}Q(t)dt \right]$$

$$\therefore DC = C_d\alpha\beta \left[\begin{array}{l} \dfrac{S\mu^{\beta}}{\beta} - \left(a\dfrac{\mu^{\beta+1}}{\beta+1} + \dfrac{b}{2}\dfrac{\mu^{\beta+2}}{\beta+2} + \dfrac{c}{3}\dfrac{\mu^{\beta+3}}{\beta+3}\right) + S_1\dfrac{(t_1-\mu)^{\beta}}{\beta} \\ -\left(a+m\mu\right)\dfrac{(t_1-\mu)^{\beta+1}}{\beta+1} - \dfrac{m}{2}\dfrac{(t_1-\mu)^{\beta+2}}{\beta+2} \end{array} \right] \quad (13)$$

5. Lost Sale Cost

$$LSC = l\int_{t_1}^{T}\left(a+mt\right)\left[1-e^{-\delta(T-t)}\right]dt$$

$$\therefore LSC = l\delta\left\{a + \left(T-t_1\right) + \left(mT-a\right)\left(\frac{T^2-t_1^2}{2}\right) - \frac{m}{2}\left(T^3-t_1^3\right)\right\} \quad (14)$$

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Hence, the average total cost for the time period [0,T] is given by

$$TC = \frac{1}{T}\left[IHC + SC + DC + LSC + OC\right]$$

$$\therefore TC = \frac{1}{T}\left[\begin{array}{l} C_h\left[\begin{array}{l}\left\{\begin{array}{l} S\left(\mu - \frac{\alpha\mu^{\beta+1}}{\beta+1}\right) - \left(\frac{a\mu^2}{2} + \frac{b\mu^3}{6} + \frac{c\mu^4}{12}\right) + \frac{a\alpha\beta\mu^{\beta+2}}{(\beta+1)(\beta+2)} \\ + \frac{b\alpha\beta\mu^{\beta+3}}{2(\beta+2)(\beta+3)} + \frac{c\alpha\beta\mu^{\beta+4}}{3(\beta+3)(\beta+4)} \end{array}\right\} + \\ \left\{\begin{array}{l} S_1\left(t_1 - \mu\right) - \frac{S_1\alpha(t_1-\mu)^{\beta+1}}{\beta+1} - \frac{\left(a+m\mu\right)(t_1-\mu)^2}{2} - \frac{m(t_1-\mu)^3}{6} \\ + \frac{\left(a+m\mu\right)\alpha\beta(t-\mu)^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{m\alpha\beta(t_1-\mu)^{\beta+3}}{2(\beta+2)(\beta+3)} \end{array}\right\} \end{array}\right] \\ +C_s\left[\begin{array}{l} a(1-\delta T)\frac{\left(T-t_1\right)^2}{2} + \frac{m(1-\delta T)+a\delta}{2}\left\{\frac{(T-t_1)^3}{3} + t_1(T-t_1)^2\right\} \\ + \frac{m\delta}{3}\left\{\frac{(T-t_1)^4}{4} + t_1(T-t_1)^3 + \frac{3t_1^2}{2}(T-t_1)^2\right\} \end{array}\right] \\ +C_d\alpha\beta\left[\begin{array}{l} \frac{S\mu^\beta}{\beta} - \left(a\frac{\mu^{\beta+1}}{\beta+1} + \frac{b}{2}\frac{\mu^{\beta+2}}{\beta+2} + \frac{c}{3}\frac{\mu^{\beta+3}}{\beta+3}\right) + S_1\frac{(t_1-\mu)^\beta}{\beta} \\ -\left(a+m\mu\right)\frac{(t_1-\mu)^{\beta+1}}{\beta+1} - \frac{m}{2}\frac{(t_1-\mu)^{\beta+2}}{\beta+2} \end{array}\right] \\ +l\delta\left\{a + \left(T-t_1\right) + \left(mT-a\right)\left(\frac{T^2-t_1^2}{2}\right) - \frac{m}{2}\left(T^3-t_1^3\right)\right\} + A \end{array}\right] \tag{15}$$

t_1* and T* are the optimum values of t_1 and T respectively, which minimize the cost function TC and they are the solutions of the equations $\frac{\partial TC}{\partial t_1} = 0$ & $\frac{\partial TC}{\partial T} = 0$ such that

$$\left.\begin{array}{l} \left[\left(\frac{\partial^2 TC}{\partial t_1^2}\right)\left(\frac{\partial^2 TC}{\partial T^2}\right) - \left(\frac{\partial^2 TC}{\partial t_1\,\partial T}\right)^2\right]_{t_1 = t_1^*,\, T = T^*} > 0 \\ \left[\frac{\partial^2 TC}{\partial t_1^2}\right]_{t_1 = t_1^*,\, T = T^*} > 0 \end{array}\right\} \tag{16}$$

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V. Numerical Example

Let us consider the following example to illustrate the above developed model, taking A = 300, $\alpha = 0.0001$, $\beta = 2.1$, $\delta = 0.0001$, $l = 10$, $C_s = 11$, $C_d = 3$, a = 2, b = 3, c = 5, $\mu = 1$ and $C_h = 5$ (with appropriate units).

The optimal values of t_1 and Tare $t_1^* = 1.793161518$, $T^* = 2.608338244$ units and the optimal total cost per unit time TC = 175.8083407 units.

VI. SENSITIVITY ANALYSIS

Sensitivity analysis depicts the extent to which the optimal solution of the model is affected by the changes in its input parameter values. Here, we study the sensitivity for the cycle length T and the average total cost TC with respect to the changes in the values of the parameters A, α, β, δ, l, a, b, c, μ, C_s, C_d and C_h.

The sensitivity analysis is performed by considering variation in each one of the above parameters keeping all other remaining parameters as fixed. The last column of the **Table – 1** gives the % changes in TC as compared to the original solution for the relevant costs.

Table – 1: Partial Sensitivity Analysis

Parameters	Change	t_1	T	TC
A	240	1.660194432	2.414909461	151.9305611
	270	1.729164091	2.515239773	164.0989931
	330	1.852996163	2.695382184	187.1201920
	360	1.909285217	2.777269269	198.0830227
α	0.00008	1.793187344	2.608353615	175.8075640
	0.00009	1.793174431	2.608345930	175.8079525
	0.00011	1.793148606	2.608330559	175.8087292
	0.00012	1.793135693	2.608322873	175.8091176
β	1.68	1.793157716	2.608336094	175.8084836
	1.89	1.793159522	2.608337085	175.8084080
	2.31	1.793163629	2.608339514	175.8082808
	2.52	1.793165802	2.608340854	175.8082271
δ	0.00008	1.793161013	2.608339040	175.8081428
	0.00009	1.793161265	2.608338642	175.8082418
	0.00011	1.793161771	2.608337846	175.8084398
	0.00012	1.793162023	2.608337448	175.8085389
l	8	1.793156126	2.608345223	175.8078690
	9	1.793158822	2.608341733	175.8081048
	11	1.793164214	2.608334755	175.8085766
	12	1.793166910	2.608331265	175.8088125

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Parameters	Change	t_1	T	TC
C_s	8.8	1.722814134	2.701796408	169.7067180
	9.9	1.760985380	2.650479161	173.0042153
	12.1	1.820661193	2.573099774	178.2231269
	13.2	1.844440530	2.543187476	180.3250209
C_d	2.4	1.793169804	2.608342855	175.8080109
	2.7	1.793165661	2.608340549	175.8081758
	3.3	1.793157375	2.608335939	175.8085058
	3.6	1.793153233	2.608333633	175.8086707
a	1.6	1.802851469	2.622434364	174.0101210
	1.8	1.797993120	2.615366848	174.9104424
	2.2	1.788356507	2.601348326	176.7038294
	2.4	1.783577933	2.594396870	177.5969216
b	2.4	1.837730667	2.673174800	171.7642340
	2.7	1.814891618	2.639949824	173.8111067
	3.3	1.772448957	2.578207057	177.7588703
	3.6	1.752672954	2.549438438	179.6653599
c	4.0	1.870985845	2.721552891	169.1053456
	4.5	1.830426696	2.662549370	172.5304934
	5.5	1.758744780	2.558271254	178.9531720
	6.0	1.726812593	2.511818944	181.9771533
μ	0.8	1.872726144	2.724088431	169.4035909
	0.9	1.831493986	2.664101476	172.7209705
	1.1	1.757206031	2.556038418	178.6569767
	1.2	1.723179053	2.506549757	181.2527864
C_h	4.0	2.003212388	2.731768145	167.8185058
	4.5	1.890847268	2.664483728	172.0864987
	5.5	1.707089493	2.560734551	179.0832002
	6.0	1.630419708	2.519838282	181.9865264

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VII. GRAPHICAL PRESENTATION

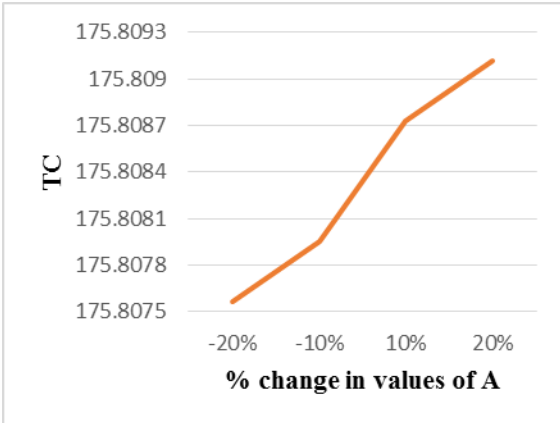

Figure – 2

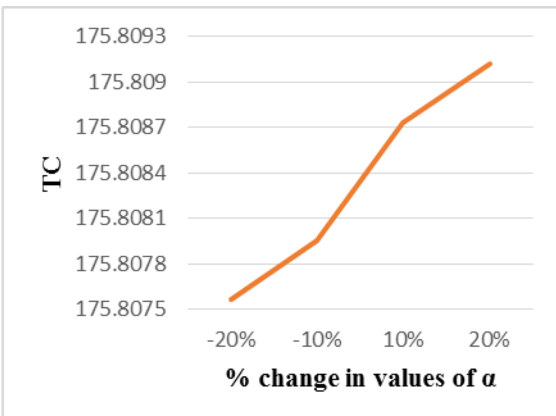

Figure – 3

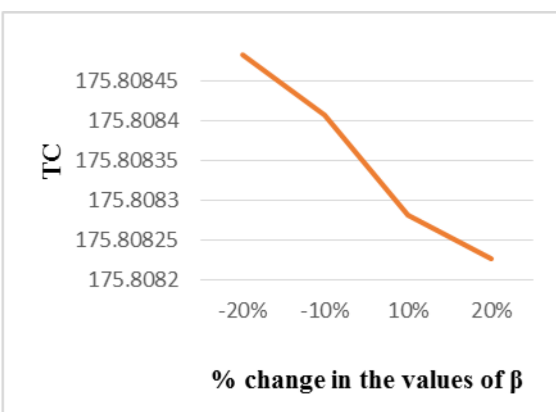

Figure – 4

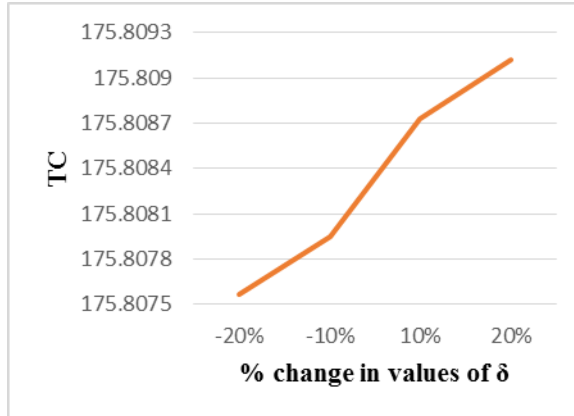

Figure – 5

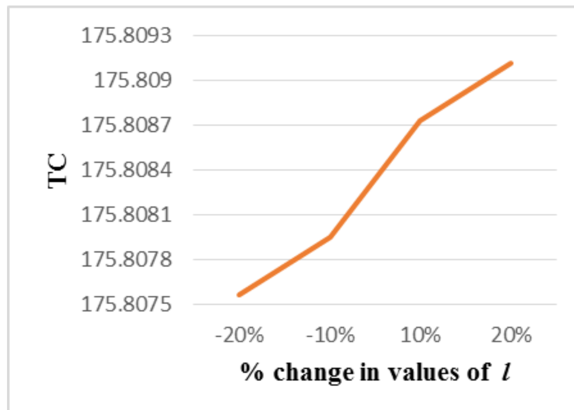

Figure – 6

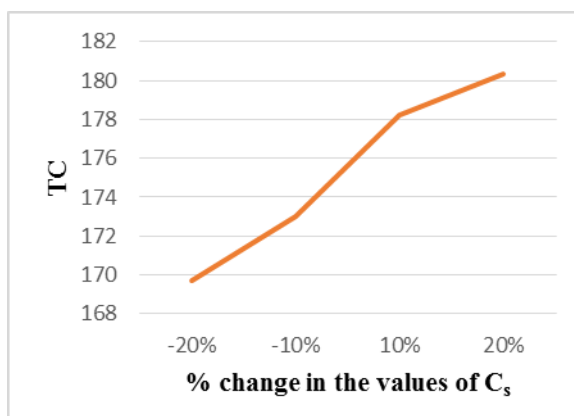

Figure – 7

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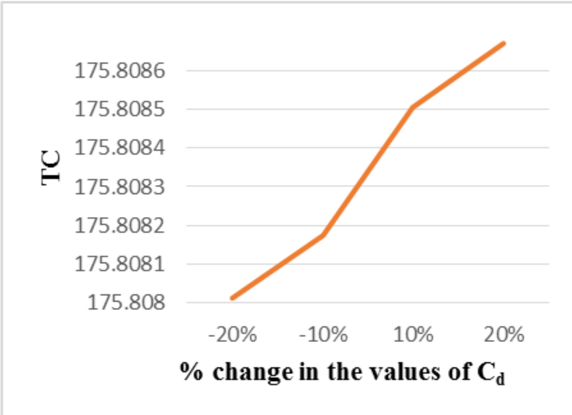

Figure – 8

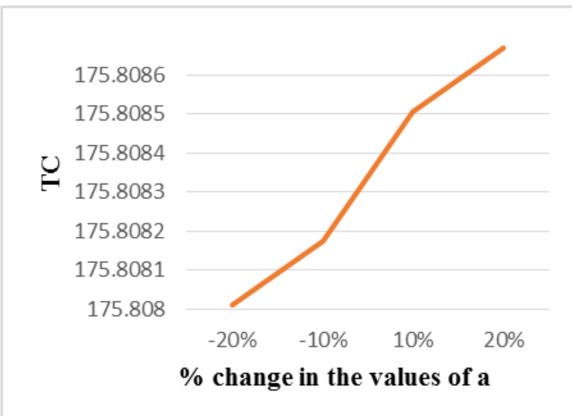

Figure – 9

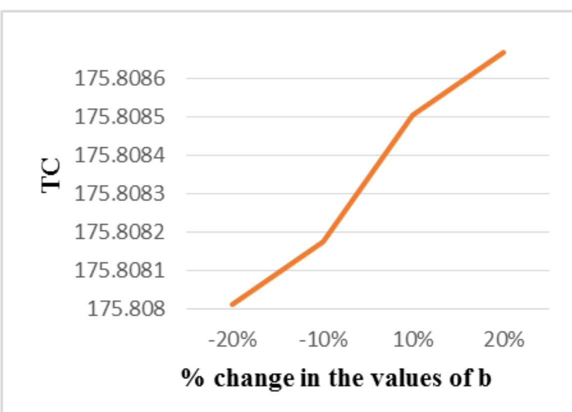

Figure – 10

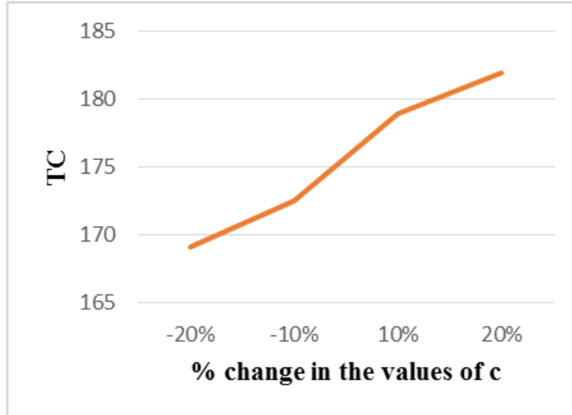

Figure – 11

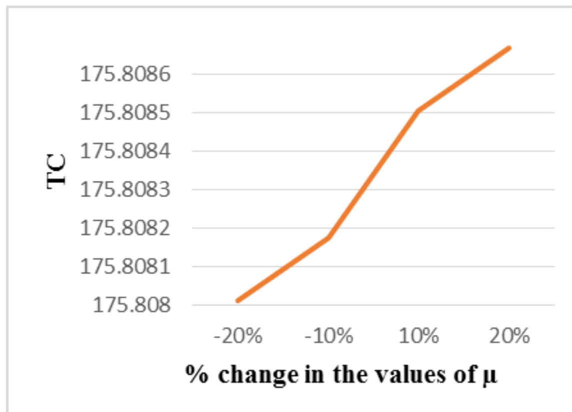

Figure – 12

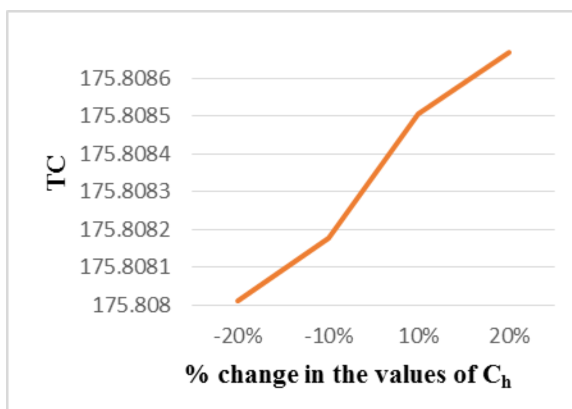

Figure – 13

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VIII. CONCLUSIONS

- From the Partial Sensitivity Analysis and Graphical Presentation it can be concluded that as the operating cost, scale parameter, backlogging parameter, lost sales cost, shortage cost, deterioration cost, constants a, b, c and location parameter μ increase, Total Cost TC also increases.

- But if the shape parameter β increases, considerable decrease in Total Cost TC is observed.

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