International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 22861-22873

http://www.ripublication.com

EOQ Model For Decaying Items With Power Demand, Partial Backlogging and Inflation

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Abstract

In this paper, an economic order quantity (EOQ) model is developed for deteriorating items with power demand pattern in which shortages are allowed and partially backlogged. The backlogging rate is taken to be inversely proportional to the waiting time for the next replenishment. In this model, we have considered two parameter Weibull distribution deterioration and power demand pattern. Scale and shape are two parameter of weibull distribution. The weibull distribution (Swedish engineer wallodi weibull) is widely used in reliability engineering. It has also been applied to many other disciplines including medicine, finance and climatology. We also considered deteriorating items such as medicine, fish, blood, alcohol, and vegetables which have finite shelf life only after the life time of items. Inflation is a global phenomenon in present day times. Inflation is very much affected by the market response to various situations. We cannot neglect importance of inflation in present work, so whole study is done in inflationary surroundings. A numerical example is provided to illustrate the model and behavior of the total cost function is shown graphically. Sensitivity analysis has been carried out for showing the effect of variation in system parameters.

Keywords: Power Demand Pattern, Weibull Deterioration, Partial Backlogging, inflation, Shortages.

Introduction

In recent years, mathematical ideas have been used in different areas in real life problems, particularly for controlling inventory. One of the important concerns of the management is to decide when and how much to order or to produce so that the total cost associated with the inventory system should be minimum. This is somewhat more important, when the inventory undergo decay or deterioration. Generally, deterioration is defined as change, damage, decay, spoilage, obsolescence and loss of utility or loss of original value in a commodity that results in the decreasing usefulness from the original one. It is well recognized fact that certain products such as vegetable, medicine, gasoline, blood and radioactive chemicals decrease under deterioration during their normal storage period. As a result, while determining the optimal inventory policy of that type of products, the loss due to deterioration cannot be ignored. A number of authors have discussed inventory models for non deteriorating items. However, there are certain substances in which deterioration plays an important role and items cannot be stored for a long time. When the items of the commodity are kept in stock as an inventory for fulfilling the future demand, there may be the deterioration of items in the inventory system. Various types of inventory models for items deteriorating at a constant rate were discussed by (Roychowdhury & Chaudhuri, 1983); (Padmanabhan & Vrat, 1995); (Balkhi & Benkherouf, 1996) and (Yang, 2005). etc. In practice it can be observed that constant rate of deterioration occurs rarely. Most of the items deteriorate fast as the time passes. Therefore, it is more realistic to consider the variable deterioration rate. In a realistic product life cycle, demand increases with time during the growth phase. A power demand pattern inventory model for deteriorating items was discussed by (Datta and Pal, 1988). (Chang & Dye, 1999). Developed an EOQ model with power demand and partial backlogging. Furthermore, when the shortage occurs, some customers are willing to wait for backorder and others would turn to buy from other sellers. Researchers such as (Park, 1982), (Hollier & Mak, 1983); (Wee, 1995) considered the constant partial backlogging rates during the shortage period in their inventory models. In many cases consumers are accustomed to a shipping delay and may be willing to wait for a short time in order to get their first choice. In some inventory systems, such as fashionable commodities, the length of the waiting time for the next replenishment would determine whether the backlogging will be accepted or not. Therefore, the backlogging rate should be variable and dependent on the length of the waiting time for the next replenishment. (Abad, 1996) investigated an EOQ model allowing shortage and partial backlogging. Many researchers have modified inventory policies by considering the "time proportional partial backlogging rate" such as (Wang, 2002); (Teng & Yang, 2004); (Wu et al., 2006); (Dye et al., 2007); (Singh et al., 2008); (Singh & Sharma, 2013 & 2014). Put forwarded interesting inventory models for deteriorating products with variable demand rate.

The effect of inflation and time-value of money cannot be overlooked in universal economics. (Buzacott, 1975); (Misra, 1975) extended the EOQ model simultaneously taking inflationary effects on costs. (Misra, 1979) derived a model with different inflation rates for various associated costs. Later, (Datta & Pal, 1991) presented the effects of inflation and time-value of money on an inventory model with time varying demand rate and shortages. (Liao et al., 2000) studied the effect of inflation on a deteriorating inventory when supplier permitted delay in payment. (Yang, 2004) developed a model for deteriorating inventory model stored at two warehouses when inflation is prevalent. (Chern et al., 2008) extended the traditional inventory lot-size model to allow for general partial backlogging rate and inflation. (Singh & Jain, 2009) developed a deterministic inventory model for deteriorating items in an inflationary environment by assuming that the retailer had the reserve money to pay off the supplier in the beginning but takes advantage of his credit period. (Yang et al., 2010) developed an inventory model for deteriorating items with partial backlogging shortages and inflation. (Yadav et al., 2013) derived retailer's optimal policy under inflation in fuzzy environment with trade-credit. (Singh & Sharma, 2013) established an integrated model with variable production and demand rate under the effect of inflation.

In the present paper a deterministic inventory model with power demand pattern is developed in which inventory is depleted not only by demand but also by deterioration. Deterioration rate is assumed to be Weibull in nature with the concept of life time of items. Shortages are allowed and partially backlogged with the time dependent backordering rate. The proposed model is developed in inflationary environment. The concept of the model is exemplified through a numerical assessment and sensitivity analysis is also performed for system parameters.

Assumptions and Notation

In developing the mathematical model of the inventory system the following assumptions and notations are being made:

1. I (t) is the inventory level at any time t, $t \geq 0$ and Q_1 is the initial inventory level.
2. μ is the life time of items and $\theta(t) = \alpha\beta t^{\beta-1}$ is two parameter Weibull deterioration. Where $0 < \alpha < 1$, $\beta > 0$ are called scale and shape parameter respectively.
3. D (t) is the demand rate at any time t, $D(t) = \dfrac{dt^{(1-n)/n}}{nT^{1/n}}$ where d is the fixed quantity, n is the parameter of power demand pattern, the value of n may be any positive number. T is the planning horizon.
4. r is the inflation rate.
5. C_1, C_h, C_d, C_s and C_l denote the ordering cost for each replenishment, inventory carrying cost per unit time, deterioration cost per unit, shortage cost for backlogged items and the unit cost of lost sales respectively.
6. Lead time is zero.
7. No replenishment or repair of deteriorated items is made during a given cycle.
8. A single item is considered over the fixed time period T units, which is subject to variable deterioration rate.
9. Deterioration of the items is considered only after the life time of items.
10. The replenishment occurs instantaneously at an infinite rate.
11. Shortages are allowed and backlogging rate is $\dfrac{dt^{(1-n)/n}}{nT^{1/n}\left(1+\delta\left(T-t\right)\right)}$, when inventory is in shortage. The backlogging parameter δ is positive constant and $0 < \delta << 1$.

Formulation and Solution of the Model

Let Q be the total amount of inventory produced or purchased at the beginning of each cycle and after fulfilling backorders let us assume we get an amount Q_1 (>0) as initial inventory. During the period (0, μ) the inventory level gradually diminishes due to market demand only. After life time deterioration take place, therefore during the period (μ, t_1) the inventory level decreases due to the demand and deterioration of items and falls to zero at time t_1. The period (t_1, T) is the period of shortage which is partially backlogged with a time dependent backlogging rate. The depletion of inventory is given in the Fig. 1.

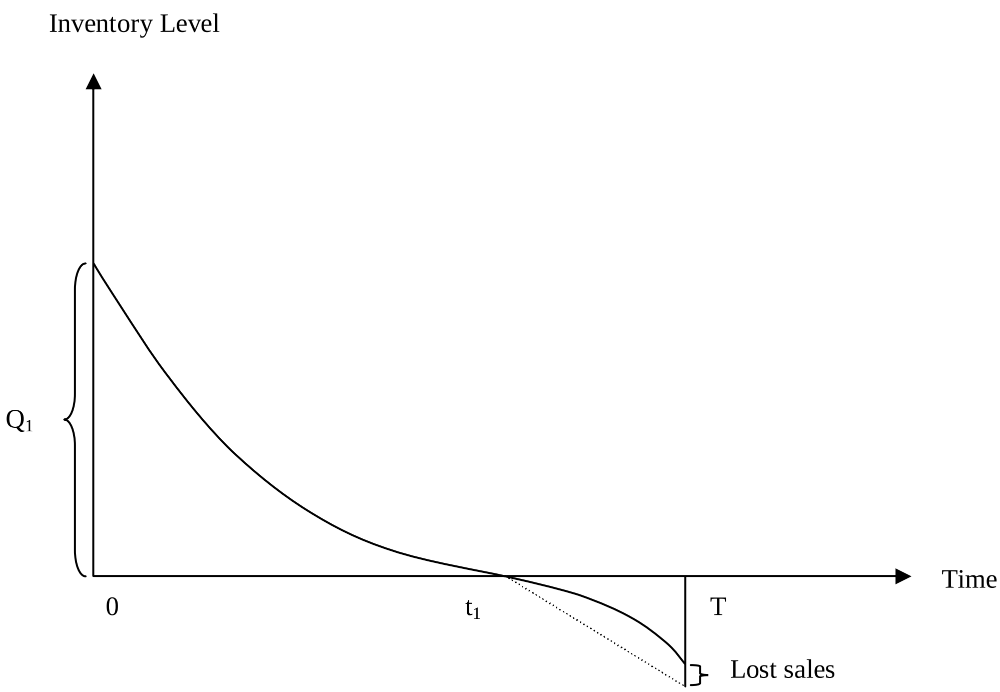

Figure 1: Inventory System With Partial Backlogging

The differential equation governing the inventory level I(t) at any time t during the cycle
(0, T) are such as

$$I'(t) = -\frac{dt^{(1-n)/n}}{nT^{1/n}} \qquad 0 \le t \le \mu \qquad (1)$$

$$I'(t) + \alpha\beta t^{\beta-1} I(t) = -\frac{dt^{(1-n)/n}}{nT^{1/n}} \qquad \mu \le t \le t_1 \qquad (2)$$

$$I'(t) = -\frac{dt^{(1-n)/n}}{\left(1+\delta\left(T-t\right)\right)nT^{1/n}} \qquad t_1 \le t \le T \qquad (3)$$

With the boundary conditions I (0) = Q_1 and I (t_1) = 0.
The solution of equation (1) is

$$I(t) = Q_1 - \frac{dt^{1/n}}{T^{1/n}} \qquad 0 \le t \le \mu \qquad (4)$$

Solution of equation (2) by taking first to terms of exponential series is

$$I(t) = \frac{d}{T^{1/n}}\left[A - \left(t^{1/n} + \frac{\alpha t^{(1/n)+\beta}}{(1+n\beta)}\right)\right]\left(1 - \alpha t^{\beta}\right) \qquad \mu \le t \le t_1 \qquad (5)$$

Where, $A = \left(t_1^{1/n} + \frac{\alpha t_1^{(1/n)+\beta}}{(1+n\beta)}\right)$

Now, solution of equation (3) is

$$I(t) = \frac{d}{T^{1/n}}\left[B - \left(t^{1/n} + \frac{\delta t^{(1/n)+1}}{(1+n)}\right)\right] \qquad t_1 \le t \le T \qquad (6)$$

Where, $B = \left((1-\delta T)t_1^{1/n} + \frac{\delta t_1^{(1/n)+1}}{(1+n)}\right)$

Since, inventory level is continuous at t = μ, so from equations (4) and (5) we get

$$Q_1 - \frac{d\mu^{1/n}}{T^{1/n}} = \frac{d}{T^{1/n}}\left[A - \left(\mu^{1/n} + \frac{\alpha\mu^{(1/n)+\beta}}{(1+n\beta)}\right)\right]\left(1 - \alpha\mu^{\beta}\right)$$

$$\Rightarrow Q_1 = \frac{d\mu^{1/n}}{T^{1/n}} + \frac{d}{T^{1/n}}\left[A - \left(\mu^{1/n} + \frac{\alpha\mu^{(1/n)+\beta}}{(1+n\beta)}\right)\right]\left(1 - \alpha\mu^{\beta}\right) \qquad (7)$$

Replenishment/Ordering cost per cycle is

$$RC = C_1 \qquad (8)$$

Inventory holding cost HC per cycle is given by

$$HC = C_h\left[\int_0^{\mu} I(t)e^{-rt}dt + \int_{\mu}^{t_1} I(t)e^{-rt}dt\right]$$

$$=C_h\left[Q_1\left(\mu-\frac{r\mu^2}{2}\right)-\frac{dn}{T^{1/n}}\left(\frac{\mu^{(1/n)+1}}{(1+n)}-\frac{r\mu^{(1/n)+2}}{(1+2n)}\right)+\frac{d}{T^{1/n}}\left\{A\left((t_1-\mu)-\frac{r}{2}\left(t_1^2-\mu^2\right)\right.\right.\right.$$

$$\left.\frac{\alpha r}{(\beta+2)}\left(t_1^{\beta+2}-\mu^{\beta+2}\right)\right)-n\left(\frac{1}{(1+n)}\left(t_1^{(1/n)+1}-\mu^{(1/n)+1}\right)-\frac{\alpha}{(1+n\beta+n)}\left(t_1^{(1/n)+\beta+1}-\mu^{(1/n)+\beta+1}\right)\right.$$

$$\left.-\frac{r}{(1+2n)}\left(t_1^{(1/n)+2}-\mu^{(1/n)+2}\right)+\frac{\alpha r}{(1+n\beta+2n)}\left(t_1^{(1/n)+\beta+2}-\mu^{(1/n)+\beta+2}\right)\right) \qquad (9)$$

$$-\frac{\alpha n}{(1+n\beta)}\left(\frac{n}{(1+n\beta+n)}\left(t_1^{(1/n)+\beta+1}-\mu^{(1/n)+\beta+1}\right)-\frac{\alpha n}{(1+2n\beta+n)}\left(t_1^{(1/n)+2\beta+1}-\mu^{(1/n)+2\beta+1}\right)\right.$$

$$\left.\left.\left.-\frac{rn}{(1+n\beta+2n)}\left(t_1^{(1/n)+\beta+2}-\mu^{(1/n)+\beta+2}\right)+\frac{\alpha rn}{(1+2n\beta+2n)}\left(t_1^{(1/n)+2\beta+2}-\mu^{(1/n)+2\beta+2}\right)\right)\right\}\right]$$

Deterioration cost DC per cycle is given by

$$DC=C_d\left[\int_{\mu}^{t_1}\alpha\beta t^{\beta-1}I(t)e^{-rt}dt\right]$$

$$=\frac{C_d\alpha\beta d}{T^{1/n}}\left[A\left\{\frac{1}{\beta}\left(t_1^{\beta}-\mu^{\beta}\right)-\frac{\alpha}{2\beta}\left(t_1^{2\beta}-\mu^{2\beta}\right)-\frac{r}{(\beta+1)}\left(t_1^{\beta+1}-\mu^{\beta+1}\right)+\frac{\alpha r}{(2\beta+1)}\times\right.\right.$$

$$\left.\left(t_1^{2\beta+1}-\mu^{2\beta+1}\right)\right\}-n\left\{\frac{1}{(1+n\beta)}\left(t_1^{(1/n)+\beta}-\mu^{(1/n)+\beta}\right)-\frac{\alpha}{(1+2n\beta)}\left(t_1^{(1/n)+2\beta}-\mu^{(1/n)+2\beta}\right)\right.$$

$$\left.-\frac{r}{(1+n\beta+n)}\left(t_1^{(1/n)+\beta+1}-\mu^{(1/n)+\beta+1}\right)+\frac{\alpha r}{(1+2n\beta+n)}\left(t_1^{(1/n)+2\beta+1}-\mu^{(1/n)+2\beta+1}\right)\right\} \qquad (10)$$

$$-\frac{\alpha n}{(1+n\beta)}\left\{\frac{1}{(1+2n\beta)}\left(t_1^{(1/n)+2\beta}-\mu^{(1/n)+2\beta}\right)-\frac{\alpha}{(1+3n\beta)}\left(t_1^{(1/n)+3\beta}-\mu^{(1/n)+3\beta}\right)\right.$$

$$\left.\left.-\frac{r}{(1+2n\beta+n)}\left(t_1^{(1/n)+2\beta+1}-\mu^{(1/n)+2\beta+1}\right)+\frac{\alpha r}{(1+3n\beta)}\left(t_1^{(1/n)+3\beta}-\mu^{(1/n)+3\beta}\right)\right\}\right]$$

Shortage cost SC per cycle is given by

$$SC=C_s\left[\int_{t_1}^{T}\left(-I(t)\right)e^{-rt}dt\right]$$

$$=\frac{C_s dn}{T^{1/n}}\left[\frac{1}{(1+n)}\left(T^{(1/n)+1}-t_1^{(1/n)+1}\right)-\frac{r}{(1+2n)}\left(T^{(1/n)+2}-t_1^{(1/n)+2}\right)-B\left\{(T-t_1)-\frac{T}{2}\left(T^2-t_1^2\right)\right\}\right.$$
$$\left.+\frac{\delta}{(1+n)}\left\{\frac{1}{(1+2n)}\left(T^{(1/n)+2}-t_1^{(1/n)+2}\right)-\frac{r}{(1+3n)}\left(T^{(1/n)+3}-t_1^{(1/n)+3}\right)\right\}\right] \quad (11)$$

Lost sales cost LC per cycle is given by

$$LC = C_l\left[\int_{t_1}^{T}\left\{1-\left(1-\delta\left(T-t\right)\right)\right\}\frac{dt^{(1-n)/n}}{nT^{1/n}}e^{-rt}dt\right]$$

$$=\frac{C_l\delta d}{T^{1/n}}\left[T\left(T^{1/n}-t_1^{1/n}\right)-\frac{(1+rT)}{(1+n)}\left(T^{(1/n)+1}-t_1^{(1/n)+1}\right)+\frac{r}{(1+2n)}\left(T^{(1/n)+2}-t_1^{(1/n)+2}\right)\right] \quad (12)$$

Therefore, total cost per unit time TAC of the system is given by

TAC (t_1) = $\frac{1}{T}$ [Replenishment cost + Holding cost + Deterioration cost + Shortage cost

+ lost sales cost] (13)

To minimize total cost per unit time TAC (t_1), the optimal value of t_1 can be obtained by solving the following equation

$$\frac{dTAC(t_1)}{dt_1}=0 \quad (14)$$

Provided this satisfies the following condition

$$\frac{d^2TAC(t_1)}{dt_1^2}>0$$

Numerical Example

To exemplify the proposed model we have taken the following data:

Let $\alpha = 0.1$, $\beta = 2$, $\delta = 0.2$, $n = 4$, $d = 60$, $\mu = 0.4$, $T = 1$, $r = 0.1$, $C_1 = 220$, $C_h = 12$, $C_d = 10$, $C_s = 4$, $C_l = 8$ in their appropriate units. Then we get the optimal solution as follows:

$t_1 = 0.6433$, $Q_1 = 46.12$ and TAC (t_1) = 305.37. The behavior of the total cost regarding time t_1 is shown in Fig. 2.

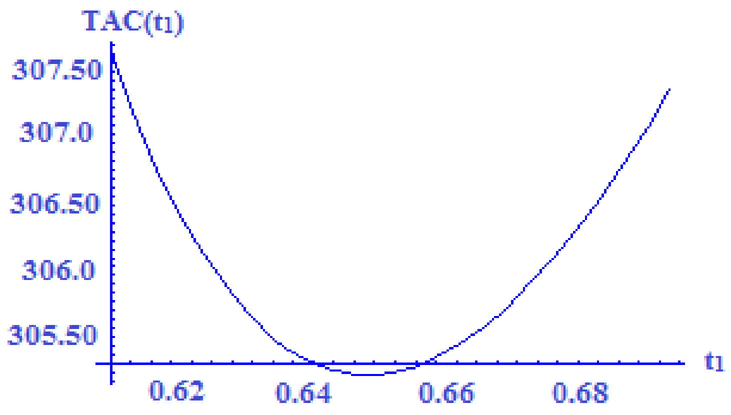

Figure 2: Behavior Of The Total Average Cost W.R.T. Time T_1.

Sensitivity Analysis

We now examine the sensitivity analysis of the optimal solution of the model for changes α, β, μ, δ and r parameter values associated with the system in the following Table 5.1. We change one parameter at a time keeping the other parameters unchanged. Sensitivity analysis is performed by changing the parameters α, β, μ, δ and r by -30%, -20%, -10%, +10%, +20%, +30% one by one in the model that are given in the following table and also graphically represented in Figs. 3-5. The initial data of all parameters have been taken from the above numerical example.

Table 5.1: Shows The Effect of Changes The Value of Α, Β, μ, Δ And R Parameter

Parameter	**% Change**	t_1	Q_1	**TAC(t_1)**
α	-30	0.6745	46.89	301.35
	-20	0.6637	46.61	302.65
	-10	0.6528	46.37	303.98
	+10	0.6398	45.85	306.48
	+20	0.6272	45.63	307.56
	+30	0.6138	45.36	308.23
β	-30	0.6596	46.32	306.89
	-20	0.6536	46.25	306.02
	-10	0.6485	46.18	305.89
	+10	0.6384	46.06	304.76
	+20	0.6325	45.98	304.15
	+30	0.6267	45.91	303.57
	-30	0.6276	45.29	303.69
	-20	0.6324	45.57	304.32

μ	-10	0.6385	45.81	304.89
	+10	0.6484	46.45	305.76
	+20	0.6525	46.78	306.15
	+30	0.6587	47.06	306.57
δ	-30	0.6216	45.72	249.56
	-20	0.6314	45.85	268.23
	-10	0.6396	45.99	286.78
	+10	0.6484	46.23	326.24
	+20	0.6575	46.35	347.13
	+30	0.6685	46.47	368.43
r	-30	0.6379	45.23	311.56
	-20	0.6398	45.58	309.54
	-10	0.6414	45.83	307.87
	+10	0.6456	46.56	303.49
	+20	0.6479	46.89	301.74
	+30	0.6496	47.15	299.55

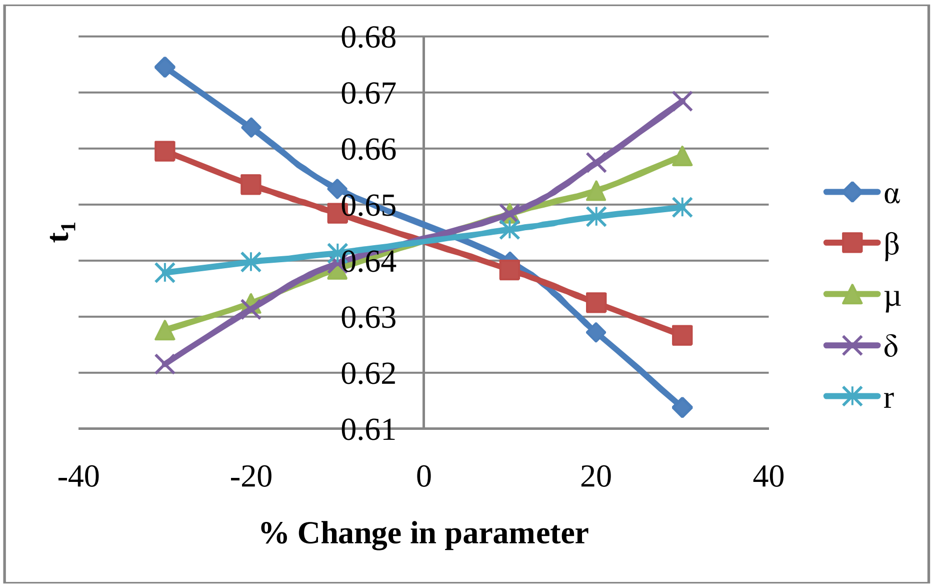

Figure 3: Behavior of Time T_1 W.R.T. Change In Parameters.

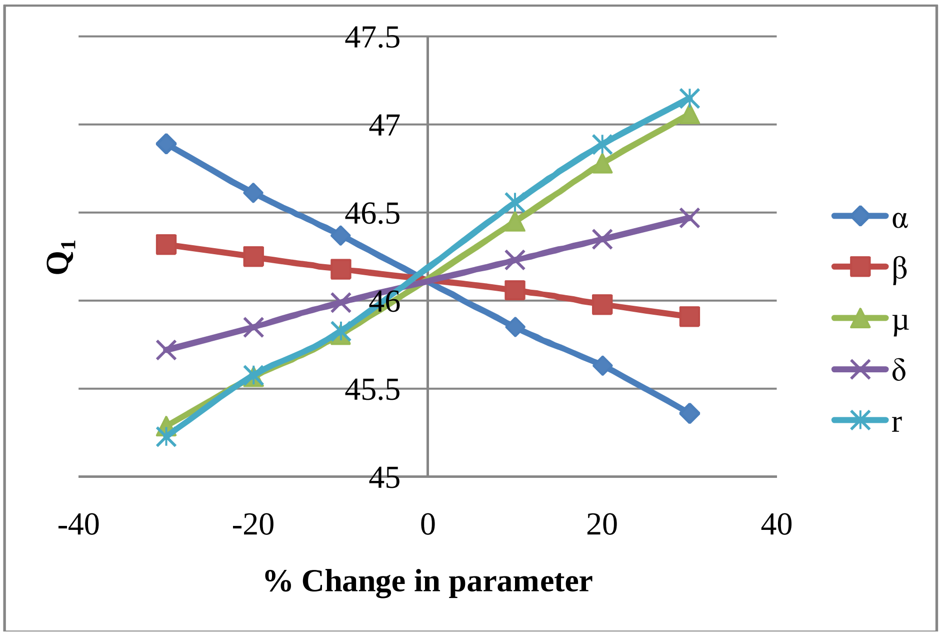

Figure 4: Behavior of Quantity Q_1 W.R.T. Change In Parameters.

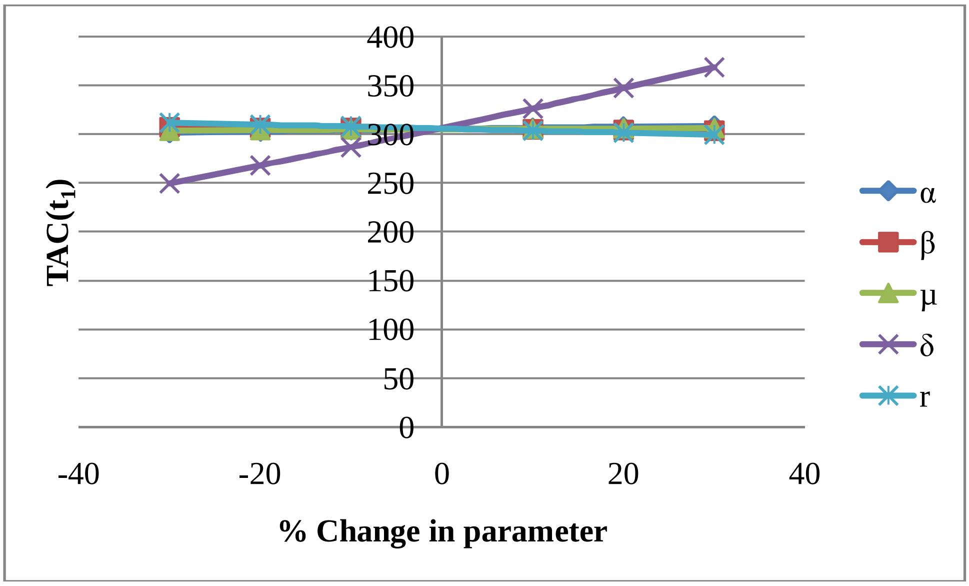

Figure 5: Behavior of total average cost TAC (t_1) w.r.t. change in parameters.

Conclusion

In the present work, we have developed an inventory model with power pattern demand with Weibull deterioration rate. Shortages are allowed and a fraction is backlogged in this model. We applied a special policy than the usual policy for such type of demand pattern which is based on Weibull distribution. We can use $n > 1$ for large portion of demand occurs at the beginning of the period and $0 < n < 1$ for maximum demand occurs at the end of interval.

Similarly $n = 1$ and $n = \infty$ corresponds to constant demand and instantaneous demand respectively. The effect of inflation is also taken into account. The model is illustrated with numerical example and convexity of the total average cost is shown graphically. Behaviors of different parameters have been illustrated with the help of sensitivity analysis. From sensitivity analysis it is observed that model is enough stable with respect to the change in system parameters.

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