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An EOQ Model for Deteriorating Items with Price Dependent Demand, Varying Holding Cost and Shortages under Trade Credit

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Abstract: ***In this research article, we developed a deterministic inventory model for price dependent demand with time dependent deterioration, varying holding cost, shortages. Credit limit is available for certain time with no interest. But after that time some interest will be charged. Customer has some reserve capital to make payment at initially but to take more benefit he use credit limit. First we developed a mathematical model after that getting the optimal solution. Numerical example is also available with graphical representation.***

Keywords: Deterioration, Price dependent demand rate, Shortages, Trade credit, holding cost.

1. Introduction

In the EOQ model, we assumed that the supplier must be paid for the items as soon as the items are received. However in practice, this may not true. In today's business transactions, it is more and more to see that a supplier will allow certain supplied. Usually there is no charge if the outstanding amount is settled within the permitted fixed settlement period, beyond this period, interest is charged.

Recently XW. Haley and R. C. Higgin (1973) developed an inventory policy and trade credit financing model. Covert R. P. and Philip G. C. (1973) develop an EOQ model for items with Weibull distribution deterioration. W. Haley and R. C. Higgin (1973) developed an inventory policy and trade credit financing model. Donaldson W. A. (1977) developed inventory replenishment policy for a linear trend in demand – an analytical solution. S. K. Goyal (1985) developed an economic order quantity model under conditions of permissible delay in payments. Dave, U. (1986), worked on an order - level inventory model for deteriorating items with variable instantaneous demand and discrete opportunities for replenishment. Goswami, A. and K. S. Chaudhuri (1991) developed an EOQ model for and inventory with a liner trend in demand and finite rate of replenishment considering shortages. K. Jaggi and S. P. Aggarwal (1994) published a model for credit financing in economic ordering policies of deteriorating items. S. P. Aggarwal and C. K. Jaggi (1995) gives a model for Ordering policies of deteriorating items under permissible delay in payments. M. M. Jamal et al (1997) gives an ordering policy model for deteriorating items with allowable shortage and permissible delay in payment. Kumar, N. and Sharma, A. K. (2001) developed an optimum ordering interval model with known demand for items with variable rate of deterioration and shortages. Mondal B. et al (2003) developed an inventory system model of ameliorating items for price dependent demand rate. Sharma, A. K. et al (2003) developed a deterministic lot size inventory model for deteriorating items when delay in payments are permissible for a system power demand pattern and random deterioration. Kumar M. et al (2008) developed optimal ordering policy and pricing with variable demand rate under trade credits. Jaggi C. K. et al (2011) produced a model for pricing and replenishment policies for imperfect quality deteriorating items under inflation and permissible delay in payments.

In reality, demand for physical goals may be time dependent, stock dependent and price dependent. Selling price plays an important role in field of inventory system. Burwell (1997) developed an economic lot size model for price dependent demand under quantity and freight discounts. Mondal et al (2003) presented an inventory system of ameliorating items for price dependent demand rate. In this paper, we developed an EOQ inventory model for deteriorating items, where deterioration rate depends on time and holding cost is linear and fully backlogged. Demand rate is a function of selling price with permission delay in payments.

2. Assumptions

1. The deterioration function $\theta(t)$ in the following form $\theta(t)=\alpha\beta t^{(\beta-1)}H(t-\mu), 0<\alpha<1$, $\beta\geq 1,\ \ t,\mu>0,\ H(t-\mu)$ is Heaviside function.
2. Shortages are allowed and are fully backlogged.
3. Demand rate is a function of selling price $f(p)=(a-p)>0$.
4. Time dependent holding cost. $h(t)=h+\alpha t$, $\alpha>0, h>0$ is the inventory holding cost per unit time.
5. No lead time.
6. Payment delay is allowed.
7. Before time t_1, inventory is depleted due to deterioration and demand of the items. At time t_1 the inventory become zero and start the shortages.

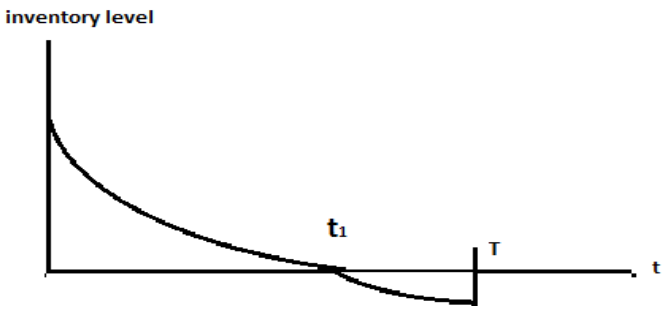
3. Notations

1. $\theta(t)=$ Inventory deterioration rate.
2. a is a parameter used in demand function and $a>p$.
3. $p=$ selling price per unit item.

4. C_1 = Inventory shortage cost per unit item.
5. C_2 = Unit cost of an item.
6. A = Order cost of an order.
7. T = Length of a cycle.
8. q = Order quantity per cycle.
9. t_1 = Length of time with positive stock.
10. Ie = Interest earned per Rs/unit time.
11. Ip = Interest paid per Rs/unit time.
12. M = Permissible delay in settling the account.

4. Mathematical Model and Solution

The inventory model with our assumption and notations is represented by the fig. 1. The inventory level $Q(t)$ with respect to time t is defined with joint effect of deterioration and demand. The inventory level decreases with time and goes to zero at time t_1. Now shortages are occurs.



For the inventory model differential equations are

$$\frac{d}{dt}Q(t) = -(a-p),\ 0 \le t \le \mu \ldots(1)$$

$$\frac{d}{dt}Q(t) + \alpha\beta t^{(\beta-1)}H(t-\mu)Q(t) = -(a-p),\ \mu \le t \le t_1 \ldots(2)$$

$$\frac{d}{dt}Q(t) = -(a-p),\ t_1 \le t \le T \ldots(3)$$

Conditions are

$Q(t) = S,$ at $t = 0$

$Q(t) = Q(\mu),$ at $t = \mu$

$Q(t) = 0,$ at $t = t_1$

Now solutions of above differential equations with conditions are

$$Q(t) = (a-p)\left\{(t_1 - t) + \frac{\alpha t_1^{(\beta+1)}}{\beta+1} - \alpha t_1 \mu^{\beta} + \frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\},\ 0 \le t \le \mu \ldots(4)$$

$$Q(t) = (a-p)\left\{(t_1 - t) + \frac{\alpha t_1^{(\beta+1)}}{\beta+1} - \alpha t_1 t^{\beta} + \frac{\alpha\beta t^{(\beta+1)}}{\beta+1}\right\},\ \mu \le t \le t_1 \ldots(5)$$

$$Q(t) = (a-p)(t_1 - t),\ t_1 \le t \le T \ldots(6)$$

Now let D be the total quantity of deteriorated items. Then

$$D = Q(\mu) - \int_{\mu}^{t_1} \alpha\beta t^{(\beta-1)} dt$$

$$D = (a-p)\left\{t_1 - \mu + \frac{\alpha t_1^{(\beta+1)}}{\beta+1} - \alpha t_1 \mu^{\beta} + \frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\} - \alpha\left(t_1^{\beta} - \mu^{\beta}\right)$$

Number of items in goods in duration [0, t_1]

$$= (a-p)\left\{\frac{t_1^2}{2} + \frac{\alpha\mu t_1^{(\beta+1)}}{\beta+1} - \frac{2\alpha t_1^{(\beta+2)}}{(\beta+1)(\beta+2)} - \frac{\alpha\beta t_1 \mu^{(\beta+1)}}{\beta+1} + \alpha\beta\mu^{(\beta+2)}\right\} \ldots(8)$$

Number of items in goods in duration [t_1, T]

$$= (a-p)\left\{Tt_1 - \frac{t_1^2}{2} - \frac{T^2}{2}\right\} \ldots(9)$$

Holding cost

$$HC = \int_0^{t_1} (h + \alpha t)Q(t)dt$$

$$HC = (a-p)\left\{\frac{-\alpha\beta h t_1 \mu^{(\beta+1)}}{\beta+1} + \frac{\alpha\beta h \mu^{(\beta+2)}}{\beta+2} - \frac{\alpha^2\beta t_1 \mu^{(\beta+2)}}{2(\beta+2)} + \frac{\alpha^2\beta^2\mu^{(\beta+3)}}{3(\beta+1)(\beta+3)} + \frac{h t_1^2}{2} + \frac{\alpha\beta h t_1^{(\beta+2)}}{(\beta+1)(\beta+2)} + \frac{\alpha t_1^3}{6} + \frac{(\beta-1)\alpha^2 t_1^{(\beta+3)}}{2(\beta+1)(\beta+2)(\beta+3)}\right\} \ldots(10)$$

Shortage cost

$$SC = C_1(a-p)\left(Tt_1 - \frac{t_1^2}{2} - \frac{T^2}{2}\right) \ldots(11)$$

Order quantity per cycle

$$q = (a-p)\left\{t_1 - \mu + \frac{\alpha t_1^{(\beta+1)}}{\beta+1} - \alpha t_1 \mu^{\beta} + \frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\} - \alpha\left(t_1^{\beta} - \mu^{\beta}\right) + (a-p)T \ldots(12)$$

Now total earned profit per cycle

$$P(T,t_1,p) = p(a-p) - \left(\frac{1}{T}\right)$$

(Annual order cost + Holding cost + shortage cost + Purchase cost + Interest charged + Interest earned)

There are three possibilities regarding the period M of permissible delay in payment.

Case 1: $M \le \mu$

Interest payble

$$IP_1 = C_2 Ip \int_M^{t_1} Q(t)dt$$

$$= C_2 Ip(a-p)\left\{-Mt_1 + \frac{M^2}{2} + \frac{\alpha\mu t_1^{(\beta+1)}}{\beta+1} - \frac{\alpha M t_1^{(\beta+1)}}{\beta+1} - \frac{\beta\mu^{(\beta+1)}}{\beta+1} + \alpha t_1 M\mu^{\beta}\right.$$

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

Interest earned

$$IE_1 = C_2 Ie\int_0^{t_1}(a-p)tdt = C_2 Ie(a-p)\frac{t_1^2}{2}$$

Total profit per unit time

$$P(T,t_1,p) = \quad p(a-p) - \left(\frac{1}{T}\right)$$ (A + HC + SC + PC + IP_1 - IE_1)

Using $t_1 = \gamma T$, where $0 < \gamma < 1$

Now profit =

$$P(T,p) = p(a-p) - \left(\frac{1}{T}\right) C_1(a-p)\left(T^2\gamma - \frac{\gamma^2T^2}{2} - \frac{T^2}{2}\right)$$

$$+(a-p)\left\{\frac{-\alpha\beta h\gamma T\mu^{(\beta+1)}}{\beta+1} + \frac{\alpha\beta h\mu^{(\beta+2)}}{\beta+2} - \frac{\alpha^2\beta\gamma T\mu^{(\beta+2)}}{2(\beta+2)} + \frac{\alpha^2\beta^2\mu^{(\beta+3)}}{3(\beta+1)(\beta+3)} + \frac{h\gamma^2T^2}{2}\right.$$

$$\left. + \frac{\alpha\beta h(\gamma T)^{(\beta+2)}}{(\beta+1)(\beta+2)} + \frac{\alpha(\gamma T)^3}{6} + \frac{(\beta-1)\alpha^2(\gamma T)^{(\beta+3)}}{2(\beta+1)(\beta+2)(\beta+3)}\right\}$$

$$+C_2(a-p)\left\{\gamma T - \mu + \frac{\alpha(\gamma T)^{(\beta+1)}}{\beta+1} - \alpha(\gamma T)\mu^{\beta} + \frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\}$$

$$-C_2\alpha\left(\gamma^{\beta}T^{\beta} - \mu^{\beta}\right) + C_2(a-p)T$$

$$+C_2 Ip(a-p)\left\{-M\gamma T + \frac{M^2}{2} + \frac{\alpha\mu(\gamma T)^{(\beta+1)}}{\beta+1} - \frac{\alpha M(\gamma T)^{(\beta+1)}}{\beta+1} - \frac{\beta\mu^{(\beta+1)}}{\beta+1} + \alpha(\gamma T)M\mu^{\beta}\right.$$

$$\left.\left. -\alpha\beta\mu^{(\beta+2)} - \frac{\alpha\beta M\mu^{(\beta+1)}}{\beta+1} + \frac{\gamma^2T^2}{2} - \frac{\alpha(\gamma T)^{(\beta+1)}}{\beta+1} + \frac{\alpha\beta(\gamma T)^{(\beta+2)}}{(\beta+1)(\beta+2)}\right\} - C_2 Ie(a-p)\frac{\gamma^2T^2}{2}\right]$$

…(13)

To maximum profit we have $\frac{\partial P}{\partial T} = 0$ and $\frac{\partial P}{\partial p} = 0$

Case 2: $\mu \le M \le t_1$

Interest payble

$$IP_2 = C_2 Ip \int_M^{t_1} Q(t)dt$$

$$= C_2 Ip(a-p)\left\{\frac{t_1^2}{2} - Mt_1 + \frac{M^2}{2} - \frac{\alpha t_1^{(\beta+1)}}{\beta+1} + \frac{\alpha t_1 M^{(\beta+1)}}{\beta+1} + \frac{\alpha\beta t_1^{(\beta+2)}}{(\beta+1)(\beta+2)} - \frac{\alpha\beta M^{(\beta+2)}}{(\beta+1)(\beta+2)}\right\}$$

Interest earned

$$IE_2 = C_2 Ie\int_0^{t_1}(a-p)t\,dt = C_2 Ie(a-p)\frac{t_1^2}{2}$$

Total profit per unit time

$$P(T,t_1,p) = \quad p(a-p) - \left(\frac{1}{T}\right)(A + HC + SC + PC + IP_2 - IE_2)$$

Using $t_1 = \gamma T$, where $0 < \gamma < 1$

Now profit =

$$P(T,p) = p(a-p) - \left(\frac{1}{T}\right) C_1(a-p)\left(T^2\gamma - \frac{\gamma^2 T^2}{2} - \frac{T^2}{2}\right)$$

$$+(a-p)\left\{\frac{-\alpha\beta h\gamma T\mu^{(\beta+1)}}{\beta+1} + \frac{\alpha\beta h\mu^{(\beta+2)}}{\beta+2} - \frac{\alpha^2\beta\gamma T\mu^{(\beta+2)}}{2(\beta+2)} + \frac{\alpha^2\beta^2\mu^{(\beta+3)}}{3(\beta+1)(\beta+3)} + \frac{h\gamma^2T^2}{2}\right.$$

$$\left.+\frac{\alpha\beta h(\gamma T)^{(\beta+2)}}{(\beta+1)(\beta+2)} + \frac{\alpha(\gamma T)^3}{6} + \frac{(\beta-1)\alpha^2(\gamma T)^{(\beta+3)}}{2(\beta+1)(\beta+2)(\beta+3)}\right\}$$

$$+C_2(a-p)\left\{\gamma T - \mu + \frac{\alpha(\gamma T)^{(\beta+1)}}{\beta+1} - \alpha(\gamma T)\mu^\beta + \frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\}$$

$$-C_2\alpha\left(\gamma^\beta T^\beta - \mu^\beta\right) + C_2(a-p)T$$

$$+C_2 Ip(a-p)\left\{\frac{\gamma^2T^2}{2} - M\gamma T + \frac{M^2}{2} + \frac{\alpha\gamma TM^{(\beta+1)}}{\beta+1} - \frac{\alpha(\gamma T)^{(\beta+1)}}{\beta+1}\right.$$

$$\left.+\frac{\alpha\beta t_1^{(\beta+2)}}{(\beta+1)(\beta+2)} - \frac{\alpha\beta M^{(\beta+2)}}{(\beta+1)(\beta+2)}\right\} - C_2 Ie(a-p)\frac{\gamma^2T^2}{2}\Bigg] \qquad \ldots(14)$$

To maximum profit we have $\frac{\partial P}{\partial T} = 0$ and $\frac{\partial P}{\partial p} = 0$

Case 3: $t_1 < M \le T$

Interest payble $IP_3 = 0$

Interest earned

$$IE_3 = C_2 Ie\int_0^{t_1} f(p)t\,dt + C_2 Ie(M - t_1)\int_0^{t_1} f(p)\,dt$$

$$= C_2 Ie.(a-p)\left(Mt_1 - \frac{t_1^2}{2}\right)$$

Total profit per unit time

$$P(T,t_1,p) = \quad p(a-p) - \left(\frac{1}{T}\right)(A + HC + SC + PC + IP_2 - IE_2)$$

Using $t_1 = \gamma T$, where $0 < \gamma < 1$

Now profit =

$$P(T,p) = p(a-p) - \left(\frac{1}{T}\right) C_1(a-p)\left(T^2\gamma - \frac{\gamma^2T^2}{2} - \frac{T^2}{2}\right)$$

$$+(a-p)\left\{\frac{-\alpha\beta h\gamma T\mu^{(\beta+1)}}{\beta+1}+\frac{\alpha\beta h\mu^{(\beta+2)}}{\beta+2}-\frac{\alpha^2\beta\gamma T\mu^{(\beta+2)}}{2(\beta+2)}+\frac{\alpha^2\beta^2\mu^{(\beta+3)}}{3(\beta+1)(\beta+3)}+\frac{h\gamma^2T^2}{2}\right.$$

$$\left.+\frac{\alpha\beta h(\gamma T)^{(\beta+2)}}{(\beta+1)(\beta+2)}+\frac{\alpha(\gamma T)^3}{6}+\frac{(\beta-1)\alpha^2(\gamma T)^{(\beta+3)}}{2(\beta+1)(\beta+2)(\beta+3)}\right\}$$

$$+C_2(a-p)\left\{\gamma T-\mu+\frac{\alpha(\gamma T)^{(\beta+1)}}{\beta+1}-\alpha(\gamma T)\mu^{\beta}+\frac{\alpha\beta\mu^{(\beta+1)}}{\beta+1}\right\}-C_2\alpha\left(\gamma^{\beta}T^{\beta}-\mu^{\beta}\right)+C_2(a-p)T$$

$$\left.-C_2Ie.(a-p)\left(M\gamma T-\frac{\gamma^2T^2}{2}\right)\right] \qquad \ldots(15)$$

To maximum profit we have $\frac{\partial P}{\partial T}=0$ and $\frac{\partial P}{\partial p}=0$

The partial differential equations in all cases will givs p* and T*. The optimal value P*(T*, p*) of the average net profit can be find by using the sufficient conditions for maximum P(T, p) are

$$\frac{\partial^2P(T,p)}{\partial T^2}<0,\ \frac{\partial^2P(T,p)}{\partial p^2}<0$$

$$\frac{\partial^2P(T,p)}{\partial T^2}.\frac{\partial^2P(T,p)}{\partial p^2}-\left(\frac{\partial^2P(T,p)}{\partial p\partial T}\right)^2>0 \text{ at}$$

$T=T^*$ and $p=p^*$

5. Numerical Examples

Case 1: $M\le\mu$

Table 1 : effect of α on Profit.

Let we take the parameters M = 0. 3, μ = 0. 4, a = 200, C_1 = 5 Rs, C_2 = 150, A = 1000, Ie = 0. 1, Ip = 0. 15, β = 1, γ = 0. 1, h = 0. 4

α	T	profit
0. 1	4840. 459	1. 292168
0. 2	2349. 082	2. 569193
0. 3	1519. 259	3. 829937
0. 4	1104. 86	5. 073186

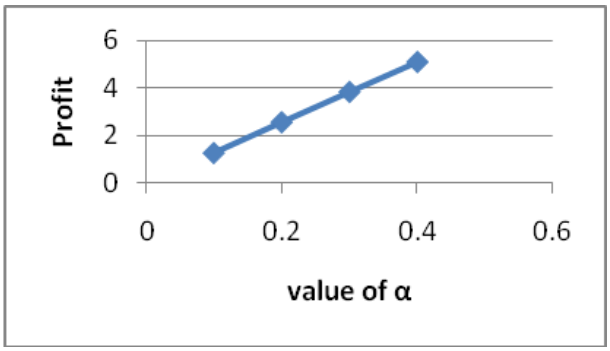


Table 2 : effect of β on Profit.

Let we take the parameters M = 0. 2, μ = 0. 4, a = 200, C_1 = 5 Rs, C_2 = 150, A = 1000, Ie = 0. 1, Ip = 0. 15, α = 0. 5, γ = 0. 1, h = 0. 4

β	T	Profit
1	853. 814	6. 293659
1. 1	530. 342	9. 219025
1. 2	357. 46	12. 46844
1. 3	256. 596	15. 86747

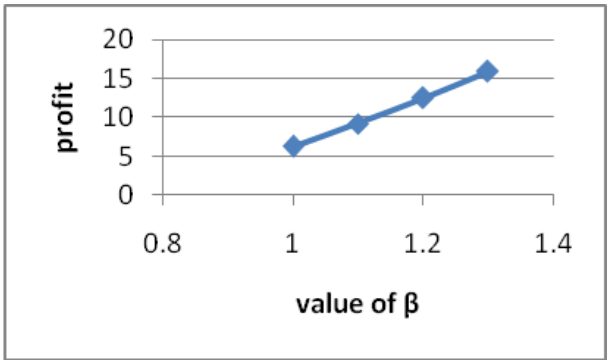


Table 3 : effect of γ on Profit.

Let we take the parameters M = 0. 2, μ = 0. 4, a = 400, C_1 = 5 Rs, C_2 = 150, A = 1000, Ie = 0. 1, Ip = 0. 15, α = 0. 5, β = 1, h = 0. 4

γ	T	Profit
0. 15	272. 222	7. 466326
0. 2	123. 294	6. 645985
0. 25	71. 127	4. 268862
0. 3	46. 823	0. 502282

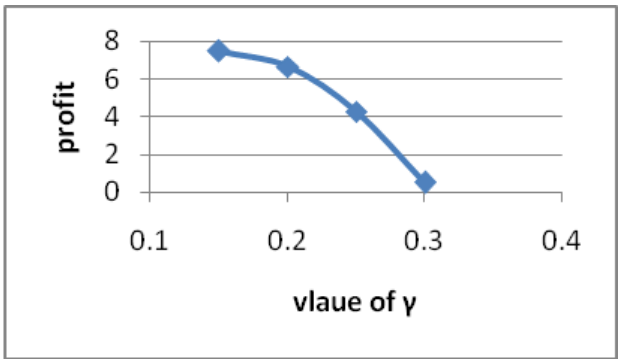
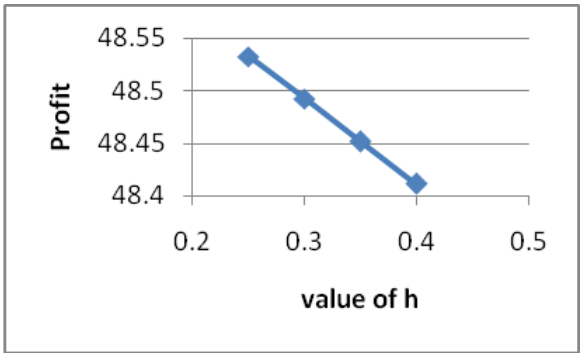


Table 4 : effect of h on Profit.

Let we take the parameters M = 0. 2, μ = 0. 4, a = 250, C_1 = 5 Rs, C_2 = 150, A = 1000, Ie = 0. 1, Ip = 0. 15, α = 0. 5, β = 2, γ = 0. 1

h	T	profit
0. 25	81. 306	48. 53274
0. 3	81. 261	48. 49209
0. 35	81. 216	48. 45145
0. 4	81. 171	48. 41079



Case 2: $\mu \le M \le t_1$

Table 5 : effect of α on Profit.

Let we take the parameters M = 2, μ = 0. 1, a = 200, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 4, Ip = 0. 1, β = 1, γ = 0. 2, h = 0. 4

α	T	Profit
0. 11	142. 17	2. 14577
0. 12	129. 77	2. 30304
0. 13	119. 282	2. 61475
0. 14	110. 295	3. 3818

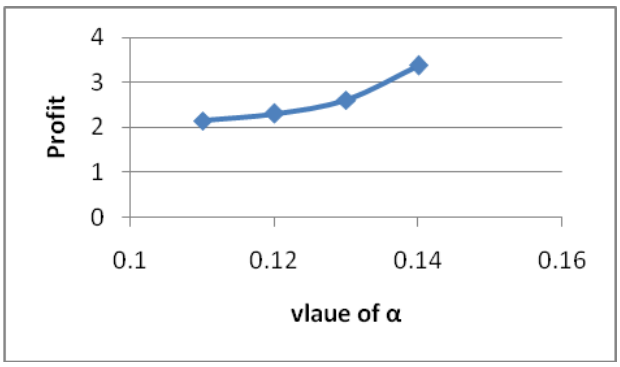


Table 6 : effect of β on Profit.

Let we take the parameters M = 2, μ = 0. 1, a = 200, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 4, Ip = 0. 1, α = 0. 1, γ = 0. 2, h = 0. 4

β	T	Profit
1	157. 03	12. 70619
1. 1	114. 285	11. 8854
1. 2	88. 013	10. 45202
1. 3	70. 776	7. 01419

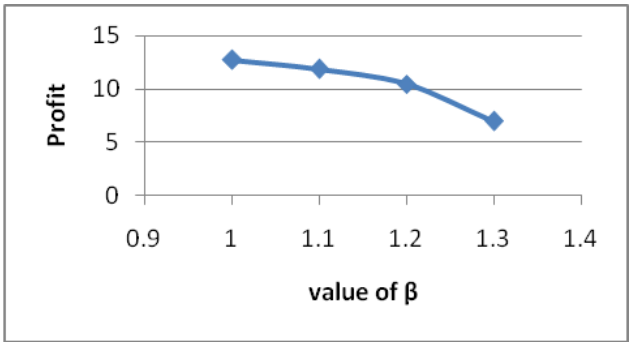


Table 7 : effect of γ on Profit.

Let we take the parameters M = 2, μ = 0. 1, a = 200, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 4, Ip = 0. 1, α = 0. 1, β = 1, h = 0. 4

γ	T	Profit
0. 1	594. 7	41. 85274
0. 15	267. 1	18. 39729
0. 2	157. 03	12. 70619
0. 25	107. 52	7. 72419

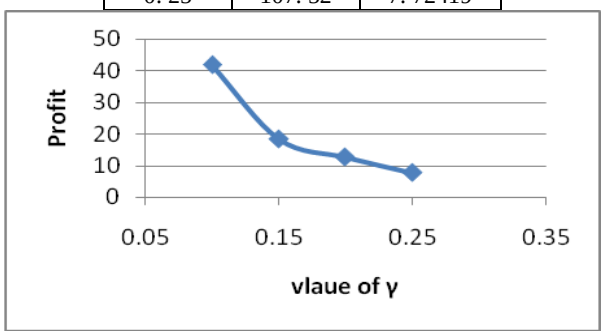
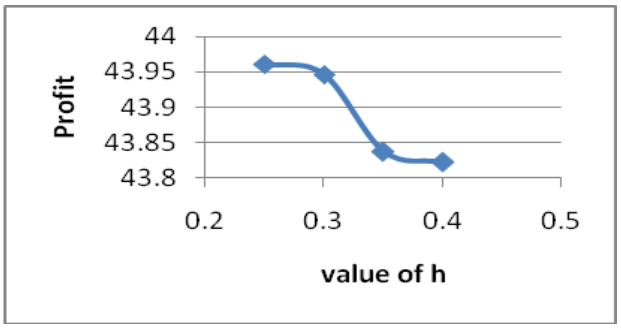


Table 8: effect of h on Profit.

Let we take the parameters M = 0. 5, μ = 0. 4, a = 250, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 1, Ip = 0. 15, α = 0. 5, β = 2, γ = 0. 2

h	T	Profit
0. 25	10. 577	43. 96146
0. 3	10. 575	43. 94658
0. 35	10. 574	43. 83763
0. 4	10. 572	43. 82295



Case 3: $t_1 < M \le T$

Table 9: effect of α on Profit.

Let we take the parameters M = 0. 3, μ = 0. 001, a = 200, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 1, Ip = 0. 15, β = 1, γ = 0. 001, h = 0. 4

α	T	Profit
0. 1	59. 795	1. 493492
0. 2	59. 8	1. 194886
0. 3	59. 805	0. 896615
0. 4	59. 81	0. 598678

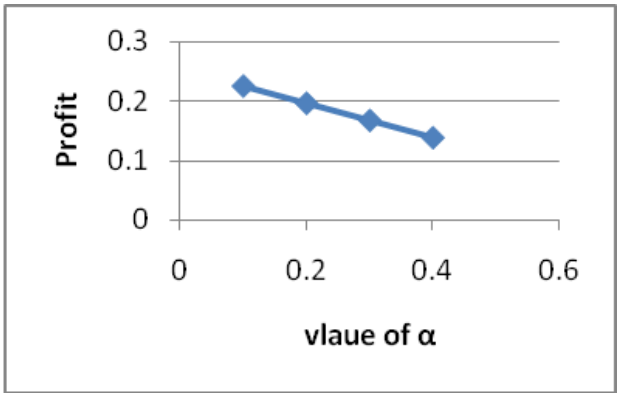
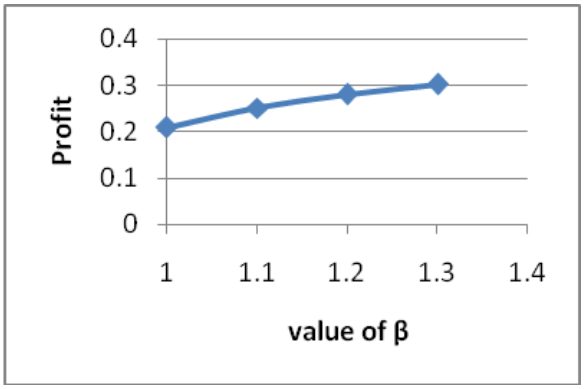


Table 10: Effect of α on Profit.
Let we take the parameters M = 0. 3, μ = 0. 001, a = 200, C_1 = 5 Rs, C_2 = 150, A = 100, Ie = 0. 1, Ip = 0. 15, α = 0. 5, γ = 0. 001, h = 0. 4

β	T	Profit
1	60. 186	0. 209164
1. 1	60. 186	0. 251115
1. 2	60. 186	0. 281028
1. 3	60. 186	0. 302274



6. Conclusion and Remarks

In the present problem a selling price dependent demand has been assumed with deterioration and holding cost is time dependent and supplier offer a trade credit time. Shortages are allowed and fully backlogged. Deterioration of items is an important factor in inventory models and cannot be avoided food items, photographic films, drugs and pharmaceuticals, chemicals, electronic component and radioactive substances are some examples of items in which deterioration may occur with time.

But at starting when an item is produced or purchased it is fresh and new and deterioration starts after a certain period. This certain period is called life time of that particular item. The life time is different for different items. The life period of items is not taken into consideration in most of the inventory models. This realistic condition of the life period of items has been considered in the present paper with selling price demand. In this paper, we study the effect of different parameters on the profit.

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