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AN INVENTORY MODEL WITH WEIBULL DISTRIBUTION DETERIORATION UNDER QUADRADIC DEMAND RATE USING PARTIAL BACKLOGGING

R. BABU KRISHNARAJ*
Associate Professor, Department of Mathematics
Hindusthan College of Arts & Science, Coimbatore – 641 028, Tamil Nadu, India.

V. NAGARANI
M. Phil (FT) Research Scholar, Department of Mathematics
Hindusthan College of Arts & Science, Coimbatore – 641 028, Tamil Nadu, India.

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ABSTRACT

Many Researchers have developed an inventory model to maximize the profit or to minimize the total cost for deteriorating items with respect to time. Deterioration in each product cannot be completely avoided and the rate of deterioration for each product will vary. We have studied an inventory model for two parameter Weibull distribution deterioration with quadratic demand rate, in which shortages are allowed and are partially backlogged and assumed that the backlogging rate is dependent on the length of the waiting time for the next replenishment. The results were described using numerical examples and sensitivity analysis.

Keywords: *Deteriorating products, partial backlogging, quadratic demand, shortage, weibull distribution and time varying holding cost.*

INTRODUCTION

The inventory control problem arises when it becomes necessary to create a stock of material resources or commodities with the purpose of meeting the demand within a given time span (finite or infinite). The challenge in any inventory control problem is to determine the quantity of products to be ordered and the moment for placing the order, which both affect the amount of the costs. Solution regarding the size of an order and the moment for its placement can be based upon the minimization of the corresponding overall costs function. The total costs of an inventory management system can be described as a function of its primary components as follows: Total cost of a inventory management system = Acquisition cost + Ordering cost + Holding cost + Deficiency losses. Recently R.Amutha and Dr.E.Chandrasekaran was developed the inventory model with weibull distribution deterioration and time-varying demand. In this paper, we have studied an inventory model for deteriorating with two parameter Weibull distribution using quadratic demand and time dependent holding cost. Shortages are allowed and are partially backlogged.

MATERIALS AND METHODS

- The inventory system deals with single item and the lead time is zero.
- Shortages are allowed and are partially backlogged. During stock out period, the backlogging rate is variable and is dependent on the length of the waiting time for next replenishment. So that the backlogging rate for negative inventory is $\beta(t) = e^{-\lambda(T-t)}$,λ is backlogging parameter and (T-t) is waiting time ($t_1 \leq t \leq T$)
- θ, be the deterioration rate. It follows the two parameter Weibull distribution $\theta(t) = \alpha\beta\, t^{\beta-1}$ where $0<\alpha<1$ and $\beta>0$
- Holding cost h(t) per item-unit is time dependent and is assumed to be $h(t) = e + dt$ when $e>0, d>0$
- T is the length of the cycle, replenishment is instantaneous at an infinite rate and the planning horizon is finite
- The demand rate is $D(t) = a + bt + ct^2$
- A,C_1, C_2, C_3&C_4 denote the set up cost, inventory carrying cost, deterioration cost per unit time, shortage cost for backlogged items and the unit cost of lost sales respectively. All the cost parameters are positive constants.

*Corresponding Author: Dr. R. Babu Krishnaraj**

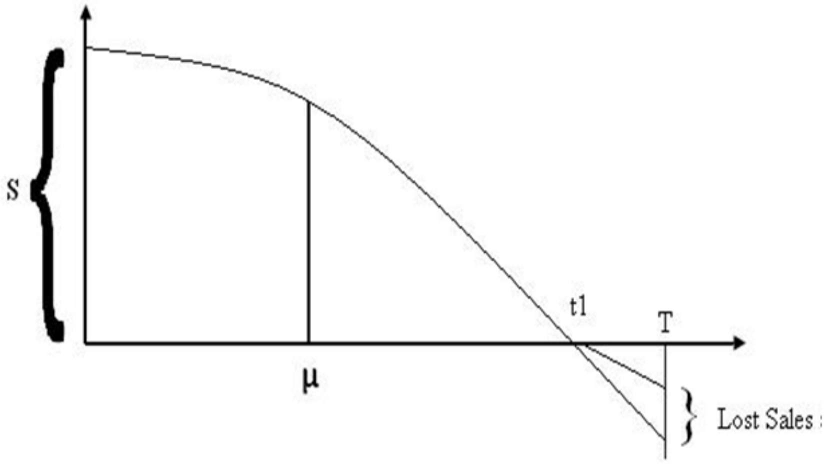

Fig.1: Graphical Representation of Inventory System

MATHEMATICAL MODEL

During the period $(0, \mu)$ the inventory level is decreasing and at time t_1 the inventory reaches zero level, where the shortage starts and in the period $(t_1,$ T) some demands are backlogged.

The rate of change of inventory during, positive stock period $(0,t_1)$ is governed by the following differential equations,

$$\frac{dI(t)}{dt} = -(a+bt+ct^2), \qquad 0 \le t \le \mu \tag{1}$$

$$\frac{dI(t)}{dt} + \alpha\beta\ t^{\beta-1} I(t) = -(a+bt+ct^2), \qquad \mu \le t \le t_1 \tag{2}$$

$$\frac{dI(t)}{dt} = -(a+bt+ct^2)e^{-\lambda(T-t)}, \qquad t_1 \le t \le T \tag{3}$$

With boundary conditions $I(0) = S,\ I(t_1) = 0$,

Solving the equations, (1), (2) and (3) and neglecting higher powers of t, we get

$$I(t) = S - \left(at + \frac{bt^2}{2} + \frac{ct^3}{3}\right) \quad 0 \le t \le \mu \tag{4}$$

$$I(t) = a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) + \frac{a\alpha}{(\beta+1)}(t_1^{\beta+1} - t^{\beta+1}) + \frac{b\alpha}{(\beta+2)}(t_1^{\beta+2} - t^{\beta+2}) + \frac{C\alpha}{\beta+3}(t_1^{\beta+3} - t^{\beta+3}) \quad \mu \le t \le t_1 \tag{5}$$

$$I(t) = a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) - a\lambda T(t_1 - t) + \frac{\lambda a}{2}(t_1^2 - t^2) - \frac{b\lambda T}{2}(t_1^2 - t^2) + \frac{b\lambda}{3}(t_1^3 - t^3) - \frac{c\lambda T}{3}(t_1^3 - t^3) + \frac{c\lambda}{4}(t_1^4 - t^4) \quad t_1 \le t \le T \tag{6}$$

From the equations (4) and (5) after replacing $t = \mu$, we get

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

$$I(\mu) = a(t_1 - \mu) + \frac{b}{2}(t_1^2 - \mu^2) + \frac{c}{3}(t_1^3 - \mu^3) + \frac{a\alpha}{\beta+1}(t_1^{\beta+1} - \mu^{\beta+1}) + \frac{b\alpha}{\beta+2}(t_1^{\beta+2} - \mu^{\beta+2}) + \frac{c\alpha}{\beta+3}(t_1^{\beta+3} - \mu^{\beta+3}) \tag{8}$$

Equating (7) and (8),

$$S = a\mu + \frac{b\mu^2}{2} + \frac{c\mu^3}{3} + a(t_1 - \mu) + \frac{b}{2}(t_1^2 - \mu^2) + \frac{c}{3}(t_1^3 - \mu^3) + \frac{a\alpha}{\beta+1}(t_1^{\beta+1} - \mu^{\beta+1})$$
$$+ \frac{b\alpha}{\beta+2}(t_1^{\beta+2} - \mu^{\beta+2}) + \frac{c\alpha}{\beta+3}(t_1^{\beta+3} - \mu^{\beta+3})$$

$$S = at_1 + \frac{bt_1^2}{2} + \frac{ct_1^3}{3} + \frac{a\alpha}{\beta+1}(t_1^{\beta+1} - \mu^{\beta+1}) + \frac{b\alpha}{\beta+2}(t_1^{\beta+2} - \mu^{\beta+2}) + \frac{c\alpha}{\beta+3}(t_1^{\beta+3} - \mu^{\beta+3}) \tag{9}$$

Using (9) in (4),

$$I(t) = S - \left(at + \frac{bt^2}{2} + \frac{ct^3}{3}\right)$$

$$I(t) = a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) + \frac{a\alpha}{\beta+1}(t_1^{\beta+1} - \mu^{\beta+1}) + \frac{b\alpha}{\beta+2}(t_1^{\beta+2} - \mu^{\beta+2}) + \frac{c\alpha}{\beta+3}(t_1^{\beta+3} - \mu^{\beta+3}) \tag{10}$$

Total amount of lost sales I_L, during the period $(0, T)$ is,

$$I_L = \int_{t_1}^{T} (1 - e^{-\lambda(T-t)})(a + bt + ct^2)dt$$

$$I_L = \frac{a\lambda T^2}{2} + \frac{b\lambda T^3}{6} + \frac{c\lambda T^4}{12} - a\lambda T t_1 + \frac{\lambda a t_1^2}{2} - \frac{b\lambda T t_1^2}{2} + \frac{b\lambda t_1^3}{3} - \frac{c\lambda T t_1^3}{3} + \frac{c\lambda t_1^4}{4} \tag{11}$$

Total amount of shortage units I_s during the period $(0, T)$ is,

$$I_S = -\int_{t_1}^{T} I(t)dt$$

$$I_S = \left\{ \begin{array}{l} -at_1T + \frac{aT^2}{2} - \frac{bt_1^2 T}{2} + \frac{bT^3}{6} - \frac{ct_1^3 T}{3} + \frac{cT^4}{12} + a\lambda T^2 t_1 - a\lambda t_1^2 T - \frac{a\lambda T^3}{3} + \frac{b\lambda T^2 t_1^2}{2} - \frac{2b\lambda t_1^3 T}{3} \\ -\frac{b\lambda T^4}{12} + \frac{c\lambda T^2 t_1^3}{3} - \frac{c\lambda T t_1^4}{2} - \frac{c\lambda T^5}{30} + \frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{a\lambda t_1^3}{3} + \frac{b\lambda t_1^4}{4} + \frac{c\lambda t_1^5}{5} \end{array} \right\} \tag{12}$$

Total amount of deterioration items I_D, during the period $(0, T)$ is,

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

$$I_D = \alpha\beta \left\{ \begin{array}{l} \frac{at_1^{\beta+1}}{\beta(\beta+1)} + \frac{bt_1^{\beta+2}}{\beta(\beta+2} + \frac{ct_1^{\beta+3}}{\beta(\beta+3)} + \frac{\alpha a t_1^{2\beta+1}}{\beta(2\beta+1)} + \frac{\alpha b t_1^{2\beta+2}}{\beta(2\beta+2} + \frac{\alpha c t_1^{2\beta+3}}{\beta(2\beta+3)} \\ -\frac{at_1\mu^{\beta}}{\beta} + \frac{a\mu^{\beta+1}}{\beta+1} - \frac{bt_1^2\mu^{\beta}}{2\beta} + \frac{b\mu^{\beta+2}}{2(\beta+2)} - \frac{ct_1^3\mu^{\beta}}{3\beta} + \frac{c\mu^{\beta+3}}{3(\beta+3)} - \frac{\alpha a t_1^{\beta+1}\mu^{\beta}}{\beta(\beta+1)} + \frac{\alpha a \mu^{2\beta+1}}{(\beta+1)(2\beta+1)} \\ -\frac{\alpha b t_1^{\beta+2}\mu^{\beta}}{\beta(\beta+2)} + \frac{\alpha b \mu^{2\beta+2}}{(2\beta+2)(\beta+2)} - \frac{\alpha c t_1^{\beta+3}\mu^{\beta}}{\beta(\beta+3)} + \frac{\alpha c \mu^{2\beta+3}}{(\beta+3)(2\beta+3)} \end{array} \right\} \tag{13}$$

During period $(0, T)$ total number of units holding I_H is,

$$I_H = \int_{0}^{\mu} (e + dt)I(t)dt + \int_{\mu}^{t1} (e + dt)I(t)dt$$

$$
\begin{aligned}
&= \int_0^{\mu} (e+dt)\{a(t_1-t)+\frac{b}{2}(t_1^2-t^2)+\frac{c}{3}(t_1^3-t^3)+\frac{\alpha a}{\beta+1}(t_1^{\beta+1}-\mu^{\beta+1})+\frac{\alpha b}{\beta+2}(t_1^{\beta+2}-\mu^{\beta+2})+ \\
&\quad +\frac{\alpha c}{\beta+3}(t_1^{\beta+3}-\mu^{\beta+3})dt\}+\int_{\mu}^{t_1}(e+dt)\{a(t_1-t)+\frac{b}{2}(t_1^2-t^2)+\frac{c}{3}(t_1^3-t^3)+\frac{\alpha a}{\beta+1}(t_1^{\beta+1}-t^{\beta+1}) \\
&\quad +\frac{\alpha b}{\beta+2}(t_1^{\beta+2}-t^{\beta+2})+\frac{\alpha c}{\beta+3}(t_1^{\beta+3}-t^{\beta+3})dt\}
\end{aligned}
$$

$$
\begin{aligned}
I_H &= \{-\frac{\alpha ae\mu^{\beta+2}}{\beta+2}-\frac{\alpha ad\,\mu^{\beta+3}}{2(\beta+3)}-\frac{\alpha be\mu^{\beta+3}}{\beta+3}-\frac{\alpha bd\,\mu^{\beta+4}}{2(\beta+4)}-\frac{\alpha ce\mu^{\beta+4}}{\beta+4}-\frac{\alpha cd\,\mu^{\beta+5}}{2(\beta+5)}+\frac{aet_1^2}{2} \\
&\quad +\frac{adt_1^3}{6}+\frac{bet_1^3}{3}+\frac{bdt_1^4}{8}+\frac{cet_1^4}{4}+\frac{cdt_1^5}{10}+\frac{\alpha aet_1^{\beta+2}}{\beta+2}+\frac{\alpha adt_1^{\beta+3}}{2(\beta+3)}+\frac{\alpha bet_1^{\beta+3}}{\beta+3}+\frac{\alpha bdt_1^{\beta+4}}{2(\beta+4)} \\
&\quad +\frac{\alpha cet_1^{\beta+4}}{\beta+4}+\frac{\alpha cdt_1^{\beta+5}}{2(\beta+5)}\ \}
\end{aligned} \tag{14}
$$

Therefore total unit cost per unit time is given by,

$$TC=\frac{1}{T}[A+C_1I_H+C_2I_D+C_3I_S+C_4I_L]$$

$$
\begin{aligned}
TC &= \frac{1}{T}[A+\frac{C_1\alpha cdt_1^{\beta+5}}{2(\beta+5)}+\frac{C_1\alpha cet_1^{\beta+4}}{\beta+4}+\frac{C_1\alpha bdt_1^{\beta+4}}{2(\beta+4)}+\frac{C_1\alpha bet_1^{\beta+3}}{\beta+3}+\frac{C_1\alpha adt_1^{\beta+3}}{2(\beta+3)}+\frac{C_1\alpha aet_1^{\beta+2}}{\beta+2} \\
&\quad +\frac{C_1cdt_1^5}{10}+\frac{C_1cet_1^4}{4}+\frac{C_1bdt_1^4}{8}+\frac{C_1bet_1^3}{3}+\frac{C_1adt_1^3}{6}+\frac{C_1aet_1^2}{2}-\frac{C_1\alpha ae\mu^{\beta+2}}{\beta+2}-\frac{C_1\alpha ad\,\mu^{\beta+3}}{2(\beta+3)} \\
&\quad -\frac{C_1\alpha be\mu^{\beta+3}}{\beta+3}-\frac{C_1\alpha bd\,\mu^{\beta+4}}{2(\beta+4)}-\frac{C_1\alpha ce\mu^{\beta+4}}{\beta+4}-\frac{C_1\alpha cd\,\mu^{\beta+5}}{2(\beta+5)}+\frac{C_2\alpha\beta at_1^{\beta+1}}{\beta(\beta+1)}+\frac{C_2\alpha\beta bt_1^{\beta+2}}{\beta(\beta+2)} \\
&\quad +\frac{c_2\alpha\beta ct_1^{\beta+3}}{\beta(\beta+3)}+\frac{c_2\alpha^2\beta at_1^{2\beta+1}}{\beta(2\beta+1)}+\frac{c_2\alpha^2\beta bt_1^{2\beta+2}}{\beta(2\beta+2)}+\frac{c_2\alpha^2\beta ct_1^{2\beta+3}}{\beta(2\beta+3)}-\frac{c_2\alpha\beta at_1\mu^{\beta}}{\beta}+\frac{c_2\alpha\beta a\mu^{\beta+1}}{\beta+1} \\
&\quad -\frac{C_2\alpha\beta bt_1^2\mu^{\beta}}{2\beta}+\frac{C_2\alpha\beta b\mu^{\beta+2}}{2(\beta+2)}-\frac{C_2\alpha\beta ct_1^3\mu^{\beta}}{3\beta}+\frac{C_2\alpha\beta c\mu^{\beta+3}}{3(\beta+3)}-\frac{C_2\alpha^2\beta at_1^{\beta+1}\mu^{\beta}}{\beta(\beta+1)} \\
&\quad +\frac{C_2\alpha^2\beta a\mu^{2\beta+1}}{(\beta+1)(2\beta+1)}-\frac{C_2\alpha^2\beta bt_1^{\beta+2}\mu^{\beta}}{\beta(\beta+2)}+\frac{C_2\alpha^2\beta b\mu^{2\beta+2}}{(2\beta+2)(\beta+2)}-\frac{C_2\alpha^2\beta ct_1^{\beta+3}\mu^{\beta}}{\beta(\beta+3)} \\
&\quad +\frac{C_2\alpha^2\beta c\mu^{2\beta+3}}{(\beta+3)(2\beta+3)}+\frac{C_3aT^2}{2}-C_3at_1T-\frac{C_3bt_1^2T}{2}+\frac{C_3bT^3}{6}-\frac{C_3ct_1^3T}{3}+\frac{C_3cT^4}{12} \\
&\quad +C_3a\lambda t_1T^2-C_3a\lambda t_1^2T-\frac{C_3a\lambda T^3}{3}+\frac{C_3b\lambda t_1^2T^2}{2}-\frac{2C_3b\lambda t_1^3T}{3}-\frac{C_3b\lambda T^4}{12} \\
&\quad +\frac{C_3c\lambda t_1^3T^2}{3}-\frac{C_3c\lambda t_1^4T}{2}-\frac{C_3c\lambda T^5}{30}+\frac{C_3at_1^2}{2}+\frac{c_3bt_1^3}{3}+\frac{c_3ct_1^4}{4}+\frac{C_3a\lambda t_1^3}{3}+\frac{C_3b\lambda t_1^4}{4} \\
&\quad +\frac{C_3c\lambda t_1^5}{5}+\frac{C_4a\lambda T^2}{2}+\frac{C_4b\lambda T^3}{6}+\frac{C_4c\lambda T^4}{12}-C_4a\lambda t_1T+\frac{C_4a\lambda t_1^2}{2}-\frac{C_4b\lambda t_1^2T}{2} \\
&\quad +\frac{C_4b\lambda t_1^3}{3}-\frac{C_4c\lambda t_1^3T}{3}+\frac{C_4c\lambda t_1^4}{4}]
\end{aligned} \tag{15}
$$

Optimal value of t_1 can be obtained by solving the equation,

$$\frac{\partial(TC)}{\partial t_1} = \frac{1}{T}\{\frac{C_1\alpha cdt_1^{\beta+4}}{2} + C_1\alpha cet_1^{\beta+3} + \frac{C_1\alpha bdt_1^{\beta+3}}{2} + C_1\alpha bet_1^{\beta+2} + C_1\alpha aet_1^{\beta+1} + \frac{C_1\alpha adt_1^{\beta+2}}{2}$$
$$+C_1aet_1 + \frac{C_1adt_1^2}{2} + C_1bet_1^2 + \frac{C_1bdt_1^3}{2} + C_1cet_1^3 + \frac{C_1cdt_1^4}{2} + \frac{C_2\alpha\beta at_1^{\beta}}{\beta} + \frac{C_2\alpha\beta bt_1^{\beta+1}}{\beta}$$
$$+\frac{C_2\alpha\beta ct_1^{\beta+2}}{\beta} + \frac{C_2\alpha^2\beta at_1^{2\beta}}{\beta} + \frac{C_2\alpha^2\beta bt_1^{2\beta+1}}{\beta} + \frac{C_2\alpha^2\beta ct_1^{2\beta+2}}{\beta} - \frac{C_2\alpha\beta a\mu^{\beta}}{\beta} - \frac{C_2\alpha\beta bt_1\mu^{\beta}}{\beta}$$
$$-\frac{C_2\alpha\beta ct_1^2\mu^{\beta}}{\beta} - \frac{C_2\alpha^2\beta at_1^{\beta}\mu^{\beta}}{\beta} - \frac{C_2\alpha^2\beta bt_1^{\beta+1}\mu^{\beta}}{\beta} - \frac{C_2\alpha^2\beta ct_1^{\beta+2}\mu^{\beta}}{\beta} - C_3aT - C_3bt_1T$$
$$-C_3ct_1^2T + C_3a\lambda T^2 \text{ - } 2C_3a\lambda t_1T + C_3b\lambda t_1T^2 - 2C_3b\lambda t_1^2T + C_3c\lambda t_1^2T^2 - 2C_3c\lambda t_1^3T$$
$$+C_3at_1 + C_3bt_1^2 + C_3ct_1^3 + C_3a\lambda t_1^2 + C_3b\lambda t_1^3 + C_3c\lambda t_1^4 - C_4a\lambda T + C_4a\lambda t_1$$
$$-C_4b\lambda t_1T + C_4b\lambda t_1^2 - C_4c\lambda t_1^2T + C_4c\lambda t_1^3\} = 0 \tag{16}$$

The minimum total average cost per unit time is obtained for those values of t_1 for which

$$\frac{\partial^2(TC)}{\partial t_1^2} > 0 \tag{17}$$

By solving equation (16), the value of t_1 can be obtained and then using this in equations (15) and (9), the optimal value of total cost (TC) and maximum inventory level (S) can be found out respectively.

NUMERICAL EXAMPLE 1

Consider an inventory model with following parameters.

For, A=50, a=25, b=400, c=20, d=0.02, e=0.5, μ=2, α=0.5, β=0.01, λ=0.8, $C_1 = 0.5$, $C_2 = 0.8, C_3 = 0.02$, C_4 =0.5, T=3 in equation (15),

We get $t_1 = 2.2961$ and using this value in equation (16), we get TC=240.4963.

SENSITIVITY ANALYSIS

Case (i): Using the above said parameters and only varying the deterioration parameter β, we get,

β	t_1	TC
0.01	2.2961	240.4963
0.02	2.2943	240.3600
0.03	2.2926	240.2447
0.04	2.2909	240.1290
0.05	2.2891	239.9911
0.06	2.2874	239.8743

RESULT

Increasing the value of deterioration parameter β, the value of t_1 and the Total Cost (TC) be decreased.

Case (ii): Using the above said parameters and only varying the deterioration parameter α, we get,

α	T_1	TC
0.4	2.3254	240.8955
0.5	2.2961	240.4963
0.6	2.2695	239.8117
0.7	2.2455	238.9070
0.8	2.2240	237.8915
0.9	2.2048	236.8135

RESULT

Increasing the value of deterioration parameter α, the value of t_1 and the Total Cost (TC) be decreased.

CONCLUSION

In this paper, we have developed a model for deteriorating item with time dependent quadratic demand and partial backlogging. From the analytical solutions of the above model it is to be concluded that the total inventory cost be minimized when we increase the deterioration rate.

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