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### An EPQ Model with Time Dependent Demand, Deterioration and Holding Cost

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**ABSTRACT:** In this paper ,an EPQ model for delayed deteriorating items is considered, where the demand before deterioration sets in is considered as time dependent quadratic and holding cost is linearly independent of time. Three stages are considered i) production build up period ii) period before deterioration starts iii) period after deterioration sets in . There is no demand during production build up period. In this model I took deterioration as a variable with respect to time( $\lambda t$ ) instead of taking constant( $\lambda$ ). In this model shortages are not allowed. The purpose of this paper is to minimizes the inventory cost per unit time. A numerical example is given to clear the applicability of the model & sensitivity analysis helps to know the effect of changes on some system parameters.

**KEYWORDS:** deterioration, Quadratic demand, EPQ model

#### I. INTRODUCTION

Demand is consumer's willingness to purchase goods or services at a particular price and time. At very beginning of production of new product demand is very low but it increases with respect to time. This model has three part .At first I consider the portion where inventory is build up. There Inventory depends production rate p. Then I consider another portion which is before deterioration starts. There depletion of inventory depend on demand. Here demand is taken as quadratic. And the last phase I consider where deterioration starts . Depletion of inventory depends on both demand rate and deterioration rate. Deterioration is variable with respect to time. In reality, holding cost and demand are time dependent. Time has essential role in inventory system. So I consider holding cost and demand as time dependent. Agatamudi and Geremew[1] considered a deterministic model with constant deterioration and power demand.Other related studies includes meenakshi & Ranjana[10], Monika and Shon [13], Ouyang et all. [16], Yang and Wee[28], Sugapriya & Jeyaraman[22], Musa& Sani[14], Dari and Sani[5,6], Baraya and Sani[2]. Biswajit and Sumon[3] developed an inventory model for time varying deterioration items with stock dependent demand where shortages are partially backlogging. Vinod [26] worked on a deterministic inventory model for non- instantaneous deterioration items in which holding cost and demand rate are a linear function of time. Umakanta, M.[23] developed an EOQ model with time dependent weibull distribution ,quadratic demand and partial backlogging. Wu et all.[27] worked on a replenishment model for non instantaneous deteriorating items with partial backlogging and stock dependent demand. Kumar et all.[9] considered an inventory model with stock dependent demand for non instantaneous deteriorating items and linear holding cost. Chang et all.[4] Developed an inventory model for non instantaneous deteriorating items where suppliers provides permissible delay payments. Geetha and Uthayakumar [7] studied an inventory policy for deteriorating items with permissible delay in payments. Karabi et al.[8], Meenakshi and Ranjana [10], Sharmila and Uthayakumar[20] and Venkateswarlu and Mohan [24] also developed inventory models with quadratic time dependent demand. Sh-Tyan[21] developed an integrated production and inventory model. Mohan[12] considered an inventory model with quadratic demand, variable holding cost and time dependent deterioration. Pando et al. [17] worked on an economic lot size inventory model where demand rate depends on stock level. Vinod et al.[25]developed a model withtime dependent demand and time varying holding cost. Osagiede& Osagiede[15] considered an inventory replenishment policy where shortages are allowed and demand is taken as quadratic. Reza and Isa[18] considered a joint pricing inventory control model for non instantaneous deteriorating items with time dependent demand. Sarkar et al. [19] developed an optimal inventory replenishment policy for a deteriorating items with time quadratic demand and time dependent partial backlogging. Mohan and Venkateswarlu [11] worked on an ordeed inventory problem where demand rate is quadratic function of time with weibull distribution and variable holding cost. Umankanta worked on ordered level inventory system with time dependent weibull deterioration ,quadratic demand rates and shortages. Mishra & Singh [29] gave a deteriorating inventory model with partial backlogging where demand and deterioration are considered as constant. R.Amutha et all[30] considered an inventory model for deteriorating products with weibull



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distribution deterioration. Pareek.S & Sharma. G[31] considered an inventory model with weibull distribution deteriorating item with partial backlogging and exponential decling demand. Vinod Kumar Mishra [32] considered an inventory model of instantaneous deteriorating items with controllable deterioration rate for time dependent demand and holding cost. Leea & Dye [33] formulated a deteriorating inventory model with stock dependent demand by allowing preservation technology cost as a decision variable in conjunction with replacement policy. Kundu.S & Chakrabarti.T [34] considered retailer's replenishment policies under trade credit depending on the ordered quantity. Kundu.S , Chakrabarti.T & Jana.K.D [35] gave a model of optimal manufacturing-remanufacturing production policy for a closed loop supply chain under fill rate and budget constraint in bi fuzzy environment. Kundu.S & Chakrabarti.T [36] considered an integrated multi stage supply chain inventory model with imperfect production process. Kundu.S & Chakrabarti.T [37] worked on joint optimal decisions on a pricing and local advertising policy of a socially responsible dual chain supply chain. Kundu.S & Chakrabarti.T[38] considered impact of carbon emission policies on manufacturing and remanufacturing and collection of used item decisions with price dependent return. Kundu.S & Chakrabarti.T[39] gave a paper on a fuzzy rough integrated multi stage supply chain inventory model with carbon emissions under inflation and time value of money. Duari.N & Chakrabarti.T [40] gave a paper on an order level EOQ Model for deteriorating items in a single warehouse system with price dependent demand and shortages.

#### **II. NOTATIONS AND ASSUMPTIONS**

#### NOTATIONS

- C The unit cost of the item.
- A The set up cost per production run.
- i The inventory carrying charge.
- d<sub>1</sub> The demand rate during the period before deterioration sets in.
- $d_2$  The demand rate after deterioration sets in.
- $\lambda$  Deterioration which is variable with time.
- L<sub>1</sub> The production build up period.
- $L_2$  The time deterioration sets in.
- Y<sub>1</sub> The inventory level at the end of production build up.
- Y<sub>2</sub> The inventory level at the time deterioration begins.
- H The holding cost in a production cycle.
- L The production cycle length.
- $Y_1(t)$  The inventory level before deterioration sets in.
- $Y_2(t)$  The inventory level after deterioration begins.

#### ASSUMPTIONS

i) Instantaneous production.

ii)Backorders are not allowed

iii)Demand before deterioration is taken as quadratic and defined by  $d_1=(C_1+C_2t+C_3t^2)$ , where  $C_3>0$ 

iv) Holding cost are taken as linear.

V)  $L_1 \leq L_2 \leq L$ 

VI)Demand of product exceeds supply.

vii)Unconstrained suppliers capital.

viii)After inspection defective items are discarded.

ix) In my model demand after deterioration sets in is assumed to be variable with time( $\lambda t$ ) instead of taking it constant( $\lambda$ ).

#### III. MATHEMATICAL MODEL DEVELOPMENT

During the buildup of inventory i.e. during production stage  $(0 \le t \le L_1)$ , there is no demand ,inventory depends on the

production rate p. Thus the differential equation that describes this situation is given by

Solution of this equation is given by

Y(t) = pt + E (where E is the integral constant) -----(2)



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Applying the initially boundary condition Y(T)=0 at t=0 in equation (2) we get E=0 -----(3) Substituting equation (3) in equation (2) equation becomes Y(t) = pt ------(4) Also from fig (1), at  $t=L_1$ ,  $Y(t)=Y_1$  substituting this into equation (4) yields  $Y_1 = PL_1 = p = Y_1/L_1$ -----(5) Substituting equation (5) into equation (4) yields  $Y(t) = \frac{Y_1}{L_1} t$  -----(6) Before deterioration sets in, depletion of inventory will depend only on demand and the differential equation which describes the situation is given by  $\frac{dY_1(t)}{dt} = -d_1$  where  $L_1 \le t \le L_2$  $= -(C_1+C_2t+C_3t^2)$ -----(7) The solution of the equation (7) is given by  $Y_1(t) = -(C_1t + C_2t^2/2 + C_3t^3/3) + k$  ------(8) As already indicated ,  $Y_1(t) = Y_1$  at  $t=L_1$  we get  $Y_{1}(t) = C_{1}(L_{1}-t) + C_{2}(L_{1}^{2}/2-t^{2}/2) + C_{3}(L_{1}^{3}/3-t^{3}/3) + Y_{1} - \dots - (9)$ Also we know  $t=L_2$ ,  $Y_1(t)=Y_2$ . By substituting this into equation (9) we get  $Y_1 = Y_2 + C_1(L_2 - L_1) + C_2(L_2^2/2 - L_1^2/2) + C_3(L_2^3/3 - L_1^3/3) - \dots$ (10) Substituting equation (10) into equation (9) we get  $Y_{1}(t) = C_{1}(L_{2}-t) + C_{2}(L_{2}^{2}/2-t^{2}/2) + C_{3}(L_{2}^{3}/3-t^{3}/3) + Y_{2} - \dots$ (11) After deterioration sets in ,depletion of inventory will depend on both demand rate and deterioration rate and the differential equation which describes the situation is given by  $\frac{dY_2(t)}{dt} + \lambda t Y_2(t) = -d_2$  $L_2 \le t \le L$  -----(12) Where deterioration is not constant, it depends with time Let us consider  $\frac{dY_2(t)}{dt} + \lambda t Y_2(t) = 0$  $\frac{dY_2(t)}{Y_2(t)} + \lambda t dt = 0$ Integrating both sides we have  $Y_2(t) = K e^{-\lambda t^2/2}$ Particular Integral= $\frac{1}{(D+\lambda t)}(-d_2)=\frac{1}{\lambda t(1+D/\lambda t)}(-d_2)=\frac{1}{\lambda t}(1+\frac{D}{\lambda t})^{-1}(-d_2)=\frac{1}{\lambda t}(1-\frac{D}{\lambda t})(-d_2)=\frac{-d^2}{\lambda t}$ 

Result is  $Y_2(t) = K \frac{e^{-\lambda t^2}}{2} - \frac{d2}{\lambda t}$  -----(13)

As already indicated at  $t=L_2$ ,  $Y_2(t)=Y_2$ , substituting this in above equation we get

$$Y_{2} = -\frac{d2}{\lambda L^{2}} + Ke^{-\lambda L^{2}/2}$$
  
Where K=(Y<sub>2</sub>+ $\frac{d2}{\lambda L^{2}}$ )  $e^{\frac{\lambda L^{2}}{2}}$   
Substituting this value of K in (13) we get  
$$Y_{2}(t) = -\frac{d2}{\lambda t} + (Y_{2} + \frac{d2}{\lambda L^{2}}) e^{\frac{\lambda (L^{2}-t^{2})}{2}} -----(14)$$

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Also when t=L, Y<sub>2</sub>(t)=0 result obtained as  $-\frac{d2}{\lambda L} + (Y_2 + \frac{d2}{\lambda L2}) e^{\frac{\lambda(L2^2 - L^2)}{2}} = 0$ We get Y<sub>2</sub> =  $\frac{d2}{\lambda} (\frac{1}{L} e^{-\lambda(L2^2 - L^2)} - \frac{1}{L2})$ ------(15) Substituting equation (15) into equations (10) & (11) respectively the results becomes Y<sub>1</sub> =  $\frac{d2}{\lambda} (\frac{1}{L} e^{-\lambda(L2^2 - L^2)} - \frac{1}{L2}) + C_1(L_2 - L_1) + C_2(L_2^2/2 - L_1^2/2) + C_3(L_2^3/3 - L_1^3/3)$ ------(16) Y<sub>1</sub>(t)=C<sub>1</sub>(L<sub>2</sub>-t)+C<sub>2</sub>(L<sub>2</sub><sup>2</sup>/2 - t<sup>2</sup>/2)+C<sub>3</sub>(L<sub>2</sub><sup>3</sup>/3 - t<sup>3</sup>/3) +  $\frac{d2}{\lambda} (\frac{1}{L} e^{-\lambda(L2^2 - L^2)} - \frac{1}{L2})$ ------(17) Substituting equation (15) into equation (14) becomes Y<sub>2</sub>(t) =  $\frac{d2}{\lambda t} (e^{\lambda(L^2 - t^2)} - 1)$ ------(18)

The no of deteriorating items  $d(L_2)$  can be considered as

$$d(L_2) = Y_2 - d_2(L-L_2)$$
  
=  $\frac{d^2}{\lambda} \left(\frac{1}{L} e^{-\lambda(L2^2 - L^2)} - \frac{1}{L^2}\right) - d_2(L-L_2)$ -----(19)

#### INVENTORY CARRYING COST(HOLDING COST)

The cost associated with storage of the whole inventory from beginning of the production until it is sold or used i,e inventory carrying cost H in a production run is given by

$$H = iC \int_0^{L_1} Y(t) dt + iC \int_{L_1}^{L_2} Y(t) dt + iC \int_{L_2}^{L} Y(t) dt - \dots$$
(20)

Substituting (6),(17)&(18) into equation (20) yields

$$H = i \int_{0}^{L_{1}} (h_{1} + h_{2}t) (\frac{\gamma_{1}}{L_{1}} t) dt + \int_{L_{1}}^{L_{2}} (h_{1} + h_{2}t) [C_{1}(L_{2} - t) + C_{2}(L_{2}^{2}/2 - t^{2}/2) + C_{3}(L_{2}^{3}/3 - t^{3}/3) + \frac{d^{2}}{\lambda t} (e^{\frac{\lambda(L^{2} - t^{2})}{2}} - 1)] dt + i \int_{L_{2}}^{L} (h_{1} + h_{2}t) \frac{d^{2}}{\lambda t} (e^{\frac{\lambda(L^{2} - t^{2})}{2}} - 1) dt$$

#### TOTAL VARIABLE COST

The total variable cost is the sum of the set up cost ,cost of deteriorated items ,and inventory carrying cost

Total variable cost per production run  $Z = A + Cd(L_2) + H$ 

Therefore the total variable cost per unit time is given by

Z(L)= Total variable cost per production The production cycle length

$$\begin{split} Z(L) &= AL + CL(D2(e-\lambda(L2-L)-1) - d_2(L-L_2)) \\ &+ iL(h_1Y_1L_12 + h_2Y_1L_1^2/3 + h_1(C_1(L_2-L_1)^2/2 + C_2(2L_2^3 - 3L_1L_2^2 + L_1^3)/6 + C_3(3L_2^4 - 4L_1L_2^3 + L_1^4)/12) \\ &+ d_2(L_2^2 - L_2^2)/2log(L_2/L_1) - (L_2-L)/L_2) \\ &+ h_2(C_1(L_2^3 - 3L_2L_1^2 - 2L_1^3)/6 + C_2(L_2^4 2L_2^2L_1^2 + L_1^4)/8 \\ &+ C_3(2L_1^5 - 5L_2^3L_1^2 - L_2^3)/30) \\ &+ (h_1d_2)/\lambda((-l_2) - \lambda L_2^2) \\ &+ (L_2^2 - L_2^2)/2log(L/L_2) - (h_2d_2)/\lambda((-L_2) - \lambda L_2^2(L-L_2) + \lambda(L_3^3 - L_2^3)/6) \\ &- (h_1d_2)/\lambda \log(L/L_2) - (h_2d_2)/\lambda((-L_2) - \lambda L_2^2(L-L_2) + \lambda(L_3^3 - L_2^3)/6) \\ &+ (h_1d_2)/\lambda(-L_2) \\ &+ (h_1d_2)/\lambda(L_2) - (h_2d_2)/\lambda((-L_2) - \lambda L_2^2(L-L_2) + \lambda(L_3^3 - L_2^3)/6) \\ &+ (h_1d_2)/\lambda(L_2) - (h_2d_2)/\lambda((-L_2) - \lambda L_2^2(L-L_2) + \lambda(L_3^3 - L_2^3)/6) \\ &+ (h_1d_2)/\lambda(L_2) \\ &+ (h_1d_2)/\lambda(L$$

Numerical examples:

By applying LINGO Software I got the value of total variable cost by putting the values of different parameters as mentioned below

c=140; A=3300 ; i=0.1; D2=2100; LAMDA=0.012 ; L1=1.547945; L2=1.8219; C1=8400; C2=4; C3=3;H1=0.1; H2=0.01; L=1.81; Y1=2853.25

We get the total variable cost = 1987.363.

Here I get the global optimum solution by using lingo software.

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#### **IV. SENSITIVITY ANALYSIS**

Total cost functions are the real solution in which different parameters are involved. It is very important to study the sensitivity i,e how parameters effects to the solution. In sensitivity analysis one parameter changes while others are kept constant and trying to find out the corresponding changes of total cost with that variable. Descriptions of different changes are mentioned below with graphical presentation.

(1) Sensitivity analysis of set up cost with Total cost:

Here set up cost is sensitive to total cost i,e set up cost changes Proportionally to total cost. As set up increases total cost increases.



(Fig-1) (Fig-2) Fig -1: stands for graphical relation of set up cost with total cost. Fig-2: stands another graphical relation of set up cost with total cost.

(2) Production built up period increases then the total variable cost per unit time decreases.

(3)As demand rate after deterioration sets in  $(d_2)$  increases the total variable cost per unit time increases.

(4) As the inventory carrying charge(i) increases total variable cost per unit time increases.

(5) As the deterioration rate( $\lambda$ ) increases the total variable cost decreases.

(6) As the unit cost of production (C) increases the total variable cost per unit time increases.

(7) As the deterioration sets  $in(L_2)$  increases, the total variable cost per unit time decreases. This is usual since as the period of the demand is high more items are going to be demanded so total variable cost per unit time decreases.

#### **V. CONCLUSION**

In this paper ,I am trying to develop an EPQ model of delayed deteriorating items which have linear holding cost and quadratic time dependent demand. The production build up of the inventory depends on the rate of production and there has no demand during production. Before deterioration sets in Demand is taken as quadratic. In this paper I am taking deterioration as time dependent variable ( $\lambda t$ ) instead of taking it as constant ( $\lambda$ ) after deterioration sets in. Demand after deterioration is taken as constant. Holding cost is taken as linear. The developed model determines total variable cost per unit time (Z) and best cycle length(L). Numerical example is given to clear the idea of the model. Sensitivity analysis has been done to see the changes of the total cost of the system by changing of the different parameters.

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