A Two Warehouse Inventory Model for Deteriorating Items with Cubic Demand, Quadratic Holding Cost and Variable Backlogging Rate

Purabi Deb Choudhury, Parag Dutta

Abstract: ***This paper deals with a two warehouse inventory model for decaying items in which demand is taken to be cubic function of time, holding cost is assumed to be quadratic function of time, backlogging rate is variable and depends on the length of the waiting time for next replenishment. Shortages are allowed in the owned warehouse. Holding cost in rented warehouse is higher than that of own warehouse. Finally the model is solved mathematically and profit maximization technique is used to illustrate the system.***

Keywords: ***Inventory, Own warehouse, Rented warehouse, Cubic demand, Quadratic holding cost***

I. INTRODUCTION

In the present competitive market situation, many of the inventory models are formulated with the assumption that all produced items are of good quality. But it is impossible for the production company to produce all the good quality products as there always remains some defective items. In reality there are so many physical goods which deteriorate during the stock in periods due to different factors like dryness, damage, spoilage and vaporization. Deterioration means worsening of products. It is a natural phenomenon in our daily life. Products like vegetables, milk, domestic goods, fashion goods; electronic components etc are deteriorating items. So this deteriorating must be considered to formulate an inventory model. During the last two decades, a number of research papers on two-warehouse inventory system have been published by several researchers. Hartely (1976) first proposed this problem in his book "Operations Research – A Managerial Emphasis". In the formulation, the transportation cost for transferring the items from RW to OW was not considered. After Hartely (1976), Sarma (1983) extended the model under the assumption that stocks of RW are transferred from RW to OW in a bulk release fashion with fixed transportation cost per unit. Dave (1988) discussed the two-warehouse inventory models for finite and infinite rate of replenishment rectifying the errors of the model developed by Sarma (1983) and gave analytical solution of each model. Further, Goswami and Chaudhuri (1992) developed the models with and without shortages for linearly time dependent demand. In their formulation, stocks of RW are transferred to OW in equal time interval. Correcting and modifying the assumptions of Goswami and Chaudhuri (1992), Bhunia and Maiti (1994) discussed the same model and graphically presented the sensitivity analyses on the optimal average cost and the cycle length for the variations on the location and shape parameters of demand. The same type of model was developed by, Kar et al. (2001), Zhou and Yang (2003) and Mondal et al. (2007) for different types of demand. Donaldson (1977) developed an optimal algorithm for solving classical no shortage inventory model. Sarma (1987) developed a two-warehouse inventory model with infinite replenishment and completely backlogged shortages. Dave (1989) proposed a deterministic lot size inventory model with shortages and a linear trend in demand. Goswami and Chaudhuri (1991) discussed different types of inventory models with linear trend in demand. Pakkala and Achary (1992) then extended Sarma's (1987) model for finite replenishment rate. All the models in Sarma (1987) and Pakkala and Achary (1992) were developed for prescribed scheduling period (cycle length), uniform demand and stocks of RW transferred to OW in continuous release fashion ignoring the transportation cost for this purpose. Benkherouf (1997) presented a two-warehouse model for deteriorating items with the general form of time dependent demand under continuous release fashion. Bhunia and Maiti (1997) discussed the same type of problem considering linearly (increasing) time dependent demand with completely backlogged shortages. This model was developed for infinite time horizon with the repetition of entire cycle with the changed value of the location parameter of the time dependent demand. Recently, very few researchers developed this type of model considering finite time horizon. All these models mentioned earlier were discussed only for non-deteriorating items. Lee and Ma (2000) developed a no-shortage inventory model for perishable items with free form of time dependent demand and fixed planning horizon. In their model, some cycles are of single warehouse system and the remaining is of two-warehouse system. Kar et al. (2001) discussed two storage inventory problems for non-perishable items with linear trend in demand over a fixed planning horizon considering lot-size dependent replenishment cost (ordering cost). On the other hand, considering two-storage facilities, Yang (2004) developed two inventory models for deteriorating items with uniform demand rate and completely backlogged shortages under inflation. Recently, Yang (2006) extended the models introduced in Yang (2004) by incorporating the partially backlogged shortages. In the year 2007, Chung and Huang (2007) proposed two-warehouse inventory model for deteriorating items. However, all these models were developed based on an impractical assumption that the

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rented warehouse has unlimited capacity.

A deterministic inventory model for deteriorating items with two warehouses is developed. Inventory cost in rented warehouse is higher than that of own warehouse. Demand is taken cubic (time dependent) in nature, holding cost is assumed to be quadratic function depending on time.

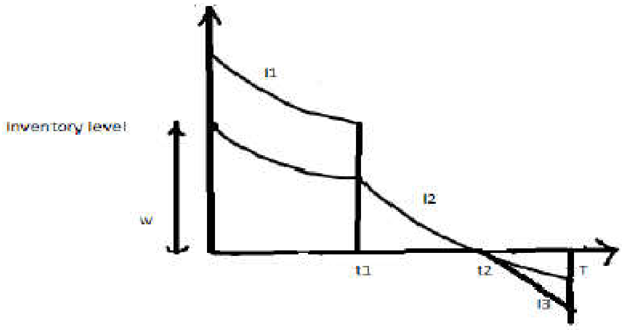
II. ASSUMPTIONS AND NOTATIONS

The following assumptions and notations have been used in developing the model:

1. Replenishment rate is infinite and lead time is constant.
2. Holding cost, demand both depends on time.
3. Shortages are allowed and unsatisfied demand in backlogged at a rate **A+Bx**, where A is constant, B is backlogging parameter (positive) and x is the waiting time.
4. Inventory cost in rented warehouse is higher than that of own warehouse.
5. Demand is assumed as, $D = a + bt + ct^2 + dt^3, where\ a, b, c, d > 0$
6. Holding cost in own warehouse assumed is $h_1 = a_1 + b_1 t + c_1 t^2$
   Holding cost in rented warehouse assumed is $h_2 = a_2 + b_2 t + c_2 t^2$ where $a_1, b_1, c_1, a_2, b_2, c_2 > 0$
7. C_s =backlogging cost per unit per unit time
8. R =opportunity cost per unit
9. T =The length of the replenishment cycle
10. t_1 =time at which the inventory level falls to zero in RW
11. t_2 =time at which the inventory level falls to zero in OW
12. RW : Rented warehouse
13. OW : Own warehouse
14. α : deterioration rate in OW
15. β : deterioration rate in RW, $0 \le \alpha, \beta < 1$
16. $I_1(t)$: Inventory level in RW at time t
17. $I_2(t)$: Inventory level in OW at time t
18. $I_3(t)$: The level of negative inventory at time t.
19. C : The purchase cost per unit.
20. C' : Ordering cost.
21. q : capacity of own warehouse
22. p : selling price per unit, where p>C
23. Q : The ordering quantity
24. S : The maximum inventory level per cycle.

III. THE MATHEMATICAL MODEL

The model begins at time t=0.Initially the business community purchases a certain amount of item from market. From which certain amount is used to meet up the backorder quantities in previous cycle and 'q' units of products are kept in OW and the remaining amount in RW. During the time interval 0≤t≤t_1 the inventory level in RW decreases due to both demand and deterioration and becomes zero at t=t_1.But in OW the inventory level q decreases during 0≤t≤t_1 ,due to deterioration only and during t_1≤t≤t_2 due to both demand and deterioration. At time t=t_2, the inventory level in OW reaches to zero. Then shortages are allowed to occur during t_2≤t≤T.Our objective is to find the maximum total average profit by considering all the relevant costs per unit time of the inventory system



(Approximate Graphical sketch of A two warehouse inventory model)

The inventory levels in RW and OW are given by the following differential equations:

$$\frac{dI_1}{dt}+\beta I_1 = -(a+bt+ct^2+dt^3) \quad , 0\le t\le t_1. \quad .... (1)$$

With the condition $I_1(t) = 0$, at $t=t_1$

And $\frac{dI_2}{dt}+\alpha I_2=0$, $0\le t\le t_1$. .... (2)

With the condition $I_2(0) = q$

The solution of (1) and (2) are,

$$I_1 = -\left[a+b\left(t_1-\frac{1}{\beta}\right)+c\left(t_1^2-\frac{4t_1}{\beta}+\frac{6}{\beta^2}\right)+d\left(t_1^3-\frac{9t_1^2}{\beta}+\frac{36t_1}{\beta^2}-\frac{60}{\beta^3}\right)\right] e^{\beta(t_1-t)} + \left[a+b\left(t-\frac{1}{\beta}\right)+c\left(t^2-\frac{4t}{\beta}+\frac{6}{\beta^2}\right)+d\left(t^3-\frac{9t^2}{\beta}+\frac{36t}{\beta^2}-\frac{60}{\beta^3}\right)\right] \quad .... (3)$$

$$I2 = qe^{-\alpha t} \quad .... (4)$$

Again during the time $t_1\le t\le t_2$, the inventory level in OW decreases due to both demand and deterioration. The differential equation involved here is:-

$$\frac{dI_2}{dt}+\alpha I_2 = -(a+bt+ct^2+dt^3) \quad , t_1\le t\le t_2$$

With the condition $I_2(t) = 0$, at $t=t_2$

Therefore,

$$I_2 = -\left[a+b\left(t_2-\frac{1}{\alpha}\right)+c\left(t_2^2-\frac{4t_2}{\alpha}+\frac{6}{\alpha^2}\right)+d\left(t_2^3-\frac{9t_2^2}{\alpha}+\frac{36t_2}{\alpha^2}-\frac{60}{\alpha^3}\right)\right] e^{\alpha(t_2-t)} + \left[a+b\left(t-\frac{1}{\alpha}\right)+c\left(t^2-\frac{4t}{\alpha}+\frac{6}{\alpha^2}\right)+d\left(t^3-\frac{9t^2}{\alpha}+\frac{36t}{\alpha^2}-\frac{60}{\alpha^3}\right)\right] \quad .... (5)$$

From (4) and (5) and due to the continuity at $t=t_1$ is,

$$I_2(t_1) = qe^{-\alpha t_1} \Rightarrow -\left[a+b\left(t_2-\frac{1}{\alpha}\right)+c\left(t_2^2-\frac{4t_2}{\alpha}+\frac{6}{\alpha^2}\right)+d\left(t_2^3-\frac{9t_2^2}{\alpha}+\frac{36t_2}{\alpha^2}-\frac{60}{\alpha^3}\right)\right] e^{\alpha(t_2-t_1)} + \left[a+b\left(t_1-\frac{1}{\alpha}\right)+c\left(t_1^2-\frac{4t_1}{\alpha}+\frac{6}{\alpha^2}\right)+d\left(t_1^3-\frac{9t_1^2}{\alpha}+\frac{36t_1}{\alpha^2}-\frac{60}{\alpha^3}\right)\right] = qe^{-\alpha t_1} \Rightarrow q = (e^{\alpha t_1}-e^{\alpha t_2})\left[a+b(t_1-t_2)+c\left(t_1^2-t_2^2-\frac{4t_1}{\alpha}+\frac{4t_2}{\alpha}\right)+d\left(t_1^3-t_2^3+\frac{9}{\alpha}(t_2^2-t_1^2)+\frac{36}{\alpha^2}(t_1-t_2)\right)\right] \Rightarrow e^{\alpha t_1}-e^{\alpha t_2} =$$

$$\frac{q}{[a+b(t_1-t_2)+c(t_1^2-t_2^2-\frac{4t_1}{\alpha}+\frac{4t_2}{\alpha})+d(t_1^3-t_2^3+\frac{9}{\alpha}(t_2^2-t_1^2)+\frac{36}{\alpha^2}(t_1-t_2)]} \Rightarrow$$

$$e^{\alpha t_2} = e^{\alpha t_1} - \frac{q}{[a+b(t_1-t_2)+c(t_1^2-t_2^2-\frac{4t_1}{\alpha}+\frac{4t_2}{\alpha})+d(t_1^3-t_2^3+\frac{9}{\alpha}(t_2^2-t_1^2)+\frac{36}{\alpha^2}(t_1-t_2)]} \Rightarrow$$

$$t_2 = \frac{\ln\left(e^{\alpha t_1} - \frac{q}{[a+b(t_1-t_2)+c(t_1^2-t_2^2-\frac{4t_1}{\alpha}+\frac{4t_2}{\alpha})+d(t_1^3-t_2^3+\frac{9}{\alpha}(t_2^2-t_1^2)+\frac{36}{\alpha^2}(t_1-t_2)]}\right)}{\alpha} \quad ----------6)$$

Again during, $t_2\le t\le T$, shortage occurs, so inventory level is backlogged follows the differential equation

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$\frac{dI_3}{dt} = -(a+bt+ct^2+dt^3)(A+Bt),\ t_1 \le t \le T$.................. (7)

With the condition $I_3(t) = 0$, at $t=t_2$

Therefore,

$I_3 = Aa(t_2-t) + (\frac{aB}{2} + \frac{Ab}{2})(t_2^2 - t^2) + (\frac{Ac}{3} + \frac{Bb}{3})(t_2^3 - t^3) + (\frac{Bc}{4} + \frac{dA}{4})(t_2^4 - t^4) + \frac{Bd}{5}(t_2^5 - t^5)$ ....(8)

The order quantity about replenishment cycle is given as,

$Q = I_1(0) + I_2(0) - I_3(T) = -[a + b(t_1 - \frac{1}{\beta}) + c(t_1^2 - \frac{4t_1}{\beta} + \frac{6}{\beta^2}) + d(t_1^3 - \frac{9t_1^2}{\beta} + \frac{36t_1}{\beta^2} - \frac{60}{\beta^3})]\, e^{\beta t_1} + [a - \frac{b}{\beta} + \frac{6c}{\beta^2} - \frac{60d}{\beta^3}] + q - [Aa(t_2 - T) + (\frac{aB}{2} + \frac{Ab}{2})(t_2^2 - T^2) + (\frac{Ac}{3} + \frac{Bb}{3})(t_2^3 - T^3) + (\frac{Bc}{4} + \frac{dA}{4})(t_2^4 - T^4) + \frac{Bd}{5}(t_2^5 - T^5)]$............................ (9)

The maximum inventory level per cycle is,

$S = I_1(0) + I_2(0)$

$= -[a + b(t_1 - \frac{1}{\beta}) + c(t_1^2 - \frac{4t_1}{\beta} + \frac{6}{\beta^2}) + d(t_1^3 - \frac{9t_1^2}{\beta} + \frac{36t_1}{\beta^2} - \frac{60}{\beta^3})]\, e^{\beta t_1} + [a - \frac{b}{\beta} + \frac{6c}{\beta^2} - \frac{60d}{\beta^3}] + q$ .... (10)

Holding cost per cycle in RW,

$C_{H_1} = \int_0^{t_1} h_2 I_1\, dt = (a - \frac{60d}{\beta^3} + \frac{6c}{\beta^2} - \frac{b}{\beta})(a_2 t_1 + b_2\frac{t_1^2}{2} + c_2\frac{t_1^3}{3}) + (b - \frac{4c}{\beta} + \frac{36d}{\beta^2})(a_2\frac{t_1^2}{2} + b_2\frac{t_1^3}{3} + c_2\frac{t_1^4}{4}) + (c - \frac{9d}{\beta})(a_2\frac{t_1^3}{3} + b_2\frac{t_1^4}{4} + c_2\frac{t_1^5}{5}) - e^{-\beta t_1}[(a - \frac{60d}{\beta^3} + \frac{6c}{\beta^2} - \frac{b}{\beta}) + (b - \frac{4c}{\beta} + \frac{36d}{\beta^2}) + (c - \frac{9d}{\beta})]\,[-\frac{a_2}{\beta} e^{-\beta t_1} + b_2(-\frac{t_1 e^{-\beta t_1}}{\beta}) - \frac{b_2}{\beta^2}(e^{-\beta t_1} - 1) - \frac{c_2}{\beta}(t_1^2 e^{-\beta t_1}) + 2\frac{c_2}{\beta}(t_1 e^{-\beta t_1}) + 2\frac{c_2}{\beta^2}(e^{-\beta t_1} - 1)]$.................(11)

Holding cost per cycle in OW,

$C_{H_2} = \int_0^{t_1} h_1 I_2\, dt + \int_{t_1}^{t_2} h_1 I_2\, dt$

$= \frac{qa_1}{\alpha} + \frac{b_1 q}{-\alpha}(t_2 e^{-\alpha t_1}) - \frac{b_1 q}{\alpha^2}(1 + e^{-\alpha t_2}) + c_1 q[-\frac{t_2^2}{\beta} e^{-\beta t_2} - \frac{2t_2}{\beta} e^{-\beta t_2} - \frac{2}{\beta^2}(1 - e^{-\beta t_2})]$ … … … ….(12)

Total holding cost, $C_H = C_{H_1} + C_{H_2}$ .... (13)

Ordering cost $= C'$

Backorder cost per cycle,

$SC = -C_s \int_{t_2}^{T} (A + Bt)\, dt = -C_s[(T - t_2)A + B\frac{T^2 - t_2^2}{2})]$.................. (14)

Opportunity cost, $OC = R(T - t_2)[1 - A - \frac{B}{2}(T + t_2)]$ .... (15)

Purchase cost per cycle, $PC = CQ$................ (16)

Sales revenue per cycle,

$SR = p\,[\int_0^{t_2}(a + bt + ct^2 + dt^3)dt + \int_{t_2}^{T}(a + bt + ct^2 + dt^3(A+Bt))dt] = p(at_2 + b\frac{t_2^2}{2} + c\frac{t_2^3}{3} + d\frac{t_2^4}{4}) + p[Aa(T - t_2) + (aB + bA)(\frac{T^2}{2} - \frac{t_2^2}{2}) + (bB + Ac)(\frac{T^3}{3} - \frac{t_2^3}{3}) + (Bc + Ad)(\frac{T^4}{4} - \frac{t_2^4}{4}) + Bd(\frac{T^5}{5} - \frac{t_2^5}{5})]$ ....(17)

Total profit per unit is,

$X = \frac{1}{T}\,[SR - OC - C_H - OC - SC - PC]$

$= \frac{1}{T}\{\, p(at_2 + b\frac{t_2^2}{2} + c\frac{t_2^3}{3} + d\frac{t_2^4}{4}) + p[Aa(T - t_2) + (aB + bA)(\frac{T^2}{2} - \frac{t_2^2}{2}) + (bB + Ac)(\frac{T^3}{3} - \frac{t_2^3}{3}) + (Bc + Ad)(\frac{T^4}{4} - \frac{t_2^4}{4}) + Bd(\frac{T^5}{5} - \frac{t_2^5}{5})] - C -$

$(a - \frac{60d}{\beta^3} + \frac{6c}{\beta^2} - \frac{b}{\beta})(a_2 t_1 + b_2\frac{t_1^2}{2} + c_2\frac{t_1^3}{3}) - (b - \frac{4c}{\beta} + \frac{36d}{\beta^2})(a_2\frac{t_1^2}{2} + b_2\frac{t_1^3}{3} + c_2\frac{t_1^4}{4}) - (c - \frac{9d}{\beta})(a_2\frac{t_1^3}{3} + b_2\frac{t_1^4}{4} + c_2\frac{t_1^5}{5}) + e^{-\beta t_1}[(a - \frac{60d}{\beta^3} + \frac{6c}{\beta^2} - \frac{b}{\beta}) + (b - \frac{4c}{\beta}$

$+ \frac{36d}{\beta^2}) + (c - \frac{9d}{\beta})]\,[-\frac{a_2}{\beta} e^{-\beta t_1} - b_2(-\frac{t_1 e^{-\beta t_1}}{\beta}) - \frac{b_2}{\beta^2}(e^{-\beta t_1} - 1) - \frac{c_2}{\beta^2}(t_1^2 - e^{-\beta t_1}) + 2\frac{c_2}{\beta}(t_1 e^{-\beta t_1}) + 2\frac{c_2}{\beta^2}(e^{-\beta t_1} - 1)]$

$+ C_s[(T - t_2)A + B(\frac{T^2 - t_2^2}{2})] - R(T - t_2)[1 - A - \frac{B}{2}(T + t_2)] - C[-\{a + b(t_1 - \frac{1}{\beta}) + c(t_1^2 - \frac{4t_1}{\beta} + \frac{6}{\beta^2}) + d(t_1^3 - \frac{9t_1^2}{\beta} + \frac{36t_1}{\beta^2} - \frac{60}{\beta^3})]\}\, e^{\beta t_1} +$

$[a - \frac{b}{\beta} + \frac{6c}{\beta^2} - \frac{60d}{\beta^3}] - Cq - C[Aa(t_2 - T) + \frac{aB}{2}(t_2^2 - T^2) + \frac{Ab}{2}(t_2^2 - T^2) + \frac{Bb}{3}(t_2^3 - T^3) + \frac{Ac}{3}(t_2^3 - T^3) + \frac{Bc}{4}(t_2^4 - T^4) + \frac{dA}{4}(t_2^4 - T^4) + \frac{Bd}{5}(t_2^5 - T^5)]\}$..(18)

Now, $\frac{\partial X}{\partial t_2} = 0$, $\frac{\partial X}{\partial T} = 0$; $\frac{\partial^2 X}{\partial t_2^2} > 0$, $\frac{\partial^2 X}{\partial T^2} > 0$ $\frac{\partial^2 X}{\partial t_2^2}\frac{\partial^2 X}{\partial T^2} - (\frac{\partial^2 X}{\partial t_2 \partial T})^2 < 0$

Numerical Illustration

Case: With shortage

q=100,a=2,b=4,c=4,d=6,α=0.05,β=0.035,C=10,C'=90,p=21,A=5,B=6t, C_s=3,R=16 in proper appropriate units, then total profit is **139309.65$**

Case: Without shortage

q=100,a=2,b=4,c=4,d=6,α=0.05,β=0.035,C=10,C'=90,p=21,A=5,B=6t in proper appropriate units, then total profit is

140000$

IV. CONCLUSION

In this paper, a two warehouse inventory model is developed considering demand as cubic function of time t, holding cost is taken to be quadratic function of time t and variable linear backlogging rate. The deterioration factor is taken in to consideration here as almost all the products will undergo decay in the course of time due different factors and different preserving facilities in both the warehouses. Also it is assumed that preserving facility of RW is better than in OW. Here demand is completely time dependent. The comparative study between the results of

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with shortage and without shortage case is also done here. A numerical illustration is there to understand the model approximately. It also shows that profit in case of without shortage case is higher than that of with shortage case. The effect of changes of parameters can also be studied.

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