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LOT SIZING DECISIONS UNDER TRADE CREDIT WITH VARIABLE DEMAND RATE UNDER INFLATION

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ABSTRACT

In this paper a model having variable demand rate for deteriorating items is considered. The factor of inflation is also considered. The concept of permissible delay has also been used. The expression for total cost of inventory is obtained first, then an optimal order quantity and maximum allowable shortages are obtained. The research will aid the retailers in economically stocking the inventory under the influence of different decision criteria such as time value of money, inflation, variable demand rate and constant deterioration rate.

Key words: *Credit period, Time dependent demand, Inflation, Shortages, discount rate.*

INTRODUCTION

In today's scenario inflation is becoming common in every developing country like India therefore to make our model more realistic we have considered the factor of inflation. In layman's language inflation is defined as rise of prices but for inventory managers it is one of the important factor to maintain their inventory. Similar is the concept of permissible delay, In general practice , a supplier are known to offer their customers a fixed period of time and do not charge any interest for this period. However, a higher interest is charged if the payment is not settled by the end of credit period . The permissible delay in payment produces two advantages to the supplier Firstly it helps to attract new customer as it can be considered some sort of loan . Secondly it helps in the bulk sale of goods. The existence of credit period serves to reduce the cost of holding stock to the user , because it reduces the amount of capital invested in stock for the duration of the credit period.

In recent years the study of deteriorating items has gained great importance.Ghare and Schrader (1973) were the first to use the concept of deterioration followed by Covert and Philip ('1973) who formulated a model with

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variable rate of deterioration with two parameter Weibull distribution, which was further extended by Shah (1977). Buzacott(1975), Bierman and Thomas (1977), investigated the inventory models with inflation followed by Mishra (1979). Mishra also developed a discount model in which the effect of both inflation and time value of money was considered. Chandra and Bhanar (1985) had also developed model under inflation and time value of money. H-J and Dye C-Y (1999**)** presented model for the situation where the demand rate is a time-continuous function and items deteriorate at a constant rate with partial backlogging. Su Chao ton, Tong Lee-Ing and Liao Hung-Chiang (1996) also developed model under inflation for stock dependent consumption rate and exponential decay. Goyal was the first to introduce the concept of permissible delay. J.T. Teng (2002) who considered the EOQ under condition of permissible delay in payment which is further extended by Ken Chung Kun and Yun-Fu-Huang (2004) for limited storage capacity. Goyal (2005) developed the optimal pricing and ordering policies for items under permissible delay.

NOTATION

α Real interest paid rupees per rupee unit time Rs/Rs yr.

f Inflation rate.

i Inventory carrying rate.

A Ordering cost of inventory, Rs./order.

β Real rate of interest earned Rupees per Rupee per unit time

S Period with shortage

T Length of inventory cycle, time units

T_1 Length of period with positive stock of the items

θ rate of deterioration per unit time

i_p $I_p - r$

r Discount rate representing the time value of money

I_p Nominal interest paid per Rupees per unit time at time

$a+bt$ time dependent demand where a and b are constant

i_e $I_e - r$

I_e Nominal interest at time t=0

$I_e(t)$ Rate of interest earned at time t, Rupees per Rupee per unit time.

$I_p(t)$ Interest rate paid at time t, Rupees per Rupee per unit time.

I_T^i Total interest earned per cycle with inflation.

M Permissible delay in settling the account.

P_T^i Interest payable per cycle with inflation.

c Unit cost of per item at time $t = 0$, Rs./unit

C_0^b Present value of the inflated backorder cost $c_{b'}$ Rs./unit

C_D^i Total cost of deterioration per cycle with inflation

C_H^i Total holding cost per cycle with inflation

D_T Amount of materials deterioration during a cycle time, T

MATHEMATICAL MODEL AND ANALYSIS

In this model variable rate of demand is considered with constant rate of deterioration. Depletion of the inventory occurs due to demand (supply) as well as due to deterioration which occurs only when there is inventory i.e., during the period $[0, T_1]$. For this period the inventory at any time t is given by :

$$\frac{dI(t)}{dt} + \theta I(t) = -(a + bt) \qquad 0 \le t \le T_1 \tag{1}$$

$$I(t). = \frac{-a}{\theta} - \frac{bt}{\theta} + \frac{b}{\theta^2} + C_1 e^{-\theta t}$$

where at t = 0, I(t) = I_0. Putting this value in the above equation, we get

$$I_0 = \frac{-a}{\theta} + \frac{b}{\theta^2} + C_1 \text{ which gives}$$

$$I(t) = I_0 e^{-\theta t} + \frac{a(e^{-\theta t} - 1)}{\theta} + \frac{b(e^{-\theta t} + 1)}{\theta^2} - \frac{bt}{\theta} \qquad 0 \le t \le T \tag{2}$$

It is obvious that at t = T_1, I (T_1) = 0. So equation (2) yields

$$I_0 = \frac{bT_1 e^{\vartheta T_1}}{\theta} + \frac{a(e^{\theta T_1} - 1)}{\theta} - \frac{b(e^{\theta T_1} - 1)}{\theta^2} = Q - b^1 \tag{3}$$

where b^1 being the maximum backorder (shortage) level permitted. Substituting the value of I_0 in eq. (2) we get

$$I(t) = \frac{b}{\theta}\left(T_1 e^{(\vartheta T_1 - \theta t)} - t\right) + \frac{a\left(e^{\theta(T_1 - t)} - 1\right)}{\theta} - \frac{b\left(e^{\theta(T_1 - t)} - 1\right)}{\theta^2} \quad 0 \le t \le T_1 \tag{4}$$

and I(t) = 0 when, $T_1 \le t \le T$. The total demand during T_1 is $\int_0^{T_1} (a + bt)\,dt$. Thus it can be easily seen that the amount of items deteriorates during one cycle is given by.

$$D_T = I_o - \int_0^{T_1} (a+bt)dt$$

$$= \frac{bT_1 e^{\vartheta T_1}}{\theta} + \frac{a(e^{\theta T_1}-1)}{\theta} - \frac{b(e^{\theta T_1}-1)}{\theta^2} - aT_1 - \frac{bT_1^{\,2}}{2} \qquad (5)$$

For inflation rate f, the continuous time inflation factor for the time period is e^{ft} which means that item costing Rs c at time t=0 will cost ce^{ft} at time t. For a discount rate, r, representing the time value of money, the present value of an amount at time t, is ce^{-rt}. Hence, the present value of the inflated price of an item at time t=0, $ce^{ft}\, e^{-rt}$ is given by

$$c_0 = ce^{(f-r)t} = ce^{Rt}, \text{ where } R = f - r \qquad (6)$$

in which c is inflated through time t to ce^{ft}, ce^{-rt} is the factor deflating the future worth to its present value and R is the present value of the inflation rate similarly, the present value of the inflated backorder cost c_b C_O^b is given by

$$C_0^b = c_b e^{(f-r)t} = c_b e^{Rt} \qquad (7)$$

THE INFLATION MODEL

There are two distinct cases in this type of inventory system

I. Payment at or before the total depletion of inventory ($M \le T_1 < T$)

II. After depletion payment ($T_1 < M$)

Case I. (i.e., payment at or before the total depletion of inventory)

(a) since the ordering is made at time t = 0, the inflation does not affect the ordering cost. Thus the ordering cost for items is fixed at A Rs/order

(b) since $I_0 = \frac{bT_1 e^{\vartheta T_1}}{\theta} + \frac{a(e^{\theta T_1}-1)}{\theta} - \frac{b(e^{\theta T_1}-1)}{\theta^2}$, the value of this inventory at time t=0 , is c $I_{0.}$ The present value of the items sold is $\int_0^{T_1} c_0 \left(a+bt\right)dt$. Hence the cost of deterioration per cycle time T under inflation, C_D^i is given by

$$C_D^i = cI_0 - \int_0^{T_1} c_0(a+bt)dt$$

$$= \frac{cbT_1e^{\vartheta T_1}}{\theta} + \frac{ca(e^{\theta T_1}-1)}{\theta} - \frac{cb(e^{\theta T_1}-1)}{\theta^2} - \frac{ca(e^{RT_1}-1)}{R} - \frac{cb(T_1e^{RT_1})}{R} + \frac{cb(e^{RT_1}-1)}{R^2} \tag{8}$$

(c) The holding cost under inflation is given by

$$C_H^i = i\int_0^{T_1} c_0 I(t)dt$$

$$= \frac{icbT_1}{\theta}\left(\frac{e^{RT_1}-e^{\vartheta T_1}}{R-\theta}\right) - \frac{icbT_1e^{RT_1}}{\theta R} + \frac{icdb}{\theta}\left(\frac{e^{RT_1}-1}{R^2}\right) + \frac{icae^{\theta T_1}}{\theta(R-\theta)}\left(e^{(R-\theta)T_1}-1\right)$$

$$-\frac{ica}{\theta}\left(\frac{e^{RT_1}-1}{R}\right) - \frac{icb}{\theta^2}\left(\frac{e^{RT_1}-e^{\theta T_1}}{R-\theta}\right) + \frac{icb}{\theta^2}\left(\frac{e^{RT_1}-1}{R}\right) \tag{9}$$

The interest payable rate at time t is $e^{I_p t}-1$ rupees per rupees, so the present value (at t = 0) of interest payable rate at time t is $I_p(t) = (e^{I_p t}-1)e^{-rt}$ rupees per rupees. Therefore the interest payable per cycle for the inventory not sold after the due date M is given by

$$P_T^i = \int_M^T cI_p(t)I(t)dt = \int_M^{T_1} cI_p(t)I(t)dt \text{ since } I(t) = 0 \text{ for } T_1 \le t \le T$$

$$= \frac{bcT_1e^{\vartheta T_1}}{\theta}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right) - \frac{bc}{\theta}\left(\frac{T_1e^{i_pT_1}-Me^{i_pM}}{i_p}\right) + \frac{bc}{\theta}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p^2}\right)$$

$$+\frac{bcT_1e^{\vartheta T_1}}{\theta}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right) - \frac{bc}{\theta}\left(\frac{T_1e^{-rT_1}-Me^{-rM}}{r}\right) - \frac{bc}{\theta}\left(\frac{e^{-rT_1}-e^{-rM}}{r^2}\right)$$

$$+\frac{ace^{\theta T_1}}{\theta}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right) + \frac{ace^{\theta T_1}}{\theta}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right) - \frac{ac}{\theta}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p}\right)$$

$$-\frac{ac}{\theta}\left(\frac{e^{-rT_1}-e^{-rM}}{r}\right) - \frac{bc}{\theta^2}e^{\theta T_1}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right)$$

$$+\frac{bc}{\theta^2}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p}\right) - \frac{bc}{\theta^2}e^{\theta T_1}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right) + \frac{bc}{\theta^2}\left(\frac{e^{-rT_1}-e^{-rM}}{r}\right) \tag{10}$$

where $i_p = I_p - r$

Similarly, the present value of the interest earned at time t, $I_e(t)$ is $(e^{Iet} - 1)e^{-rt}$. Considering inflated unit cost at time t as $c_t = ce^{Rt}$, the interest earned per cycle, I_T^i, is the interest earned up to time T_1 and it is given by

$$I_T^i = \int_0^T c_o I_e(t)(a+bt)dt$$

$$= \frac{caT_1e^{(R+i_e)T_1}}{(R+i_e)} - ca\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^2}\right) + cbT_1^2\frac{e^{(R+i_e)T_1}}{R+i_e} - cb\left(\frac{2T_1e^{(R+i_e)T_1}}{(R+i_e)^2}\right) + 2cb\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^3}\right)$$

$$-\frac{caT_1e^{(R-r)T_1}}{(R-r)} + ca\left(\frac{e^{(R-r)T_1}-1}{(R-r)^2}\right) - cbT_1^2\frac{e^{(R-r)T_1}}{R-r} + cb\left(\frac{2T_1e^{(R-r)T_1}}{(R-r)^2}\right) - 2cb\left(\frac{e^{(R-r)T_1}-1}{(R-r)^3}\right) \quad .11$$

The backorder cost per cycle under inflation, C_B^i is given by

$$C_B^i = \int_0^{T-T_1} c_b e^{R(T_1+t)}(a+bt)dt \quad \text{Since the backorder starts at } t=T_1$$

$$= c_b e^{RT_1}\frac{a}{R^2}\left[\left(RT - RT_1 - 1\right)e^{R(T-T_1)} + 1\right]$$

$$+\frac{c_b e^{RT_1} b}{R^3}\left[\left(R^2T^2 + R^2T_1^2 + 2R^2TT_1 - 2RT + 2RT_1 + 2\right)e^{R(T-T_1)} - 2\right] \quad (12)$$

THE VARIABLE COST FUNCTION

The total variable cost per cycle C_{VT}, is defined as

$$C_{VT}(T_1, T) = A + C_D^i + C_H^i + P_T^i - I_T^i + C_B^i \quad (13)$$

Substituting the values from equation (8)-(12) in equation (13), we have C_{VT} in terms of T_1 and T

$$C_{VT} = A + \frac{cbT_1e^{\vartheta T_1}}{\theta} + \frac{ca(e^{\theta T_1}-1)}{\theta} - \frac{cb(e^{\theta T_1}-1)}{\theta^2} - \frac{ca(e^{RT_1}-1)}{R} - \frac{cb(T_1e^{RT_1})}{R} + \frac{cb(e^{RT_1}-1)}{R^2}$$

$$\frac{icbT_1}{\theta}\left(\frac{e^{RT_1}-e^{\vartheta T_1}}{R-\theta}\right) - \frac{icbT_1e^{RT_1}}{\theta R} + \frac{icb}{\theta}\left(\frac{e^{RT_1}-1}{R^2}\right) + \frac{icae^{\theta T_1}}{\theta(R-\theta)}\left(e^{(R-\theta)T_1}-1\right)$$

$$-\frac{ica}{\theta}\left(\frac{e^{RT_1}-1}{R}\right)-\frac{icb}{\theta^2}\left(\frac{e^{RT_1}-e^{\theta T_1}}{R-\theta}\right)+\frac{icb}{\theta^2}\left(\frac{e^{RT_1}-1}{R}\right)$$

$$+\frac{bcT_1e^{\vartheta T_1}}{\theta}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right)-\frac{bc}{\theta}\left(\frac{T_1e^{i_pT_1}-Me^{i_pM}}{i_p}\right)+\frac{bc}{\theta}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p^2}\right)$$

1

$$+\frac{bcT_1e^{\vartheta T_1}}{\theta}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right)-\frac{bc}{\theta}\left(\frac{T_1e^{-rT_1}-Me^{-rM}}{r}\right)-\frac{bc}{\theta}\left(\frac{e^{-rT_1}-e^{-rM}}{r^2}\right)$$

$$+\frac{ace^{\theta T_1}}{\theta}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right)+\frac{ace^{\theta T_1}}{\theta}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right)-\frac{ac}{\theta}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p}\right)$$

$$-\frac{ac}{\theta}\left(\frac{e^{-rT_1}-e^{-rM}}{r}\right)-\frac{bc}{\theta^2}e^{\theta T_1}\left(\frac{e^{(i_p-\theta)T_1}-e^{(i_p-\theta)M}}{i_p-\theta}\right)$$

$$+\frac{bc}{\theta^2}\left(\frac{e^{i_pT_1}-e^{i_pM}}{i_p}\right)-\frac{bc}{\theta^2}e^{\theta T_1}\left(\frac{e^{-(r+\theta)T_1}-e^{-(r+\theta)M}}{r+\theta}\right)+\frac{bc}{\theta^2}\left(\frac{e^{-rT_1}-e^{-rM}}{r}\right)$$

$$-\frac{caT_1e^{(R+i_e)T_1}}{(R+i_e)}+ca\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^2}\right)-cbT_1^2\frac{e^{(R+i_e)T_1}}{R+i_e}+cb\left(\frac{2T_1e^{(R+i_e)T_1}}{(R+i_e)^2}\right)+2cb\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^3}\right)$$

$$+c_be^{RT_1}\frac{a}{R^2}\left[\left(RT-RT_1-1\right)e^{R(T-T_1)}+1\right]$$

$$+\frac{c_be^{RT_1}b}{R^3}\left[\left(R^2T^2+R^2T_1^2+2R^2TT_1-2RT+2RT_1+2\right)e^{R(T-T_1)}-2\right] \qquad (14)$$

MULTIPLE INVENTORIES CYCLE PER YEAR

The inflation and time value of money exist for each cycle of replenishment, so we need to consider the effect over the time horizon NT. Let there be N complete cycle during a year. Hence, NT=1. The total cost during total time is given by

$$C_T=C_{VT}\times\left[1+e^{2RT}+e^{3RT}+\dots\dots+e^{(N-1)RT}\right]=C_{VT}\times\left[\frac{1-e^{NRT}}{1-e^{RT}}\right]=C_{VT}\times\left[\frac{1-e^{R}}{1-e^{RT}}\right] \qquad (15)$$

The value of T and T_1 which minimize C_T may be obtained by simultaneously solving

$$\frac{\partial C_T}{\partial T}(T_1, T) = 0 \text{ and } \frac{\partial C_T}{\partial T_1}(T_1, T) = 0$$

Now $$\frac{\partial C_T}{\partial T} = \frac{\partial C_{VT}}{\partial T} \times \left(\frac{1-e^R}{1-e^{RT}}\right) + C_{VT} \times \frac{\partial}{\partial T}\left(\frac{1-e^R}{1-e^{RT}}\right) \tag{16}$$

in which

$$\frac{\partial C_{VT}}{\partial T} = c_b a(T-T_1)e^{RT} + 4\frac{c_b}{R} bT_1 e^{RT} + c_b b\left(T^2 + T_1^2 + 2T_1\right)e^{RT} = S$$

and

$$\frac{\partial}{\partial T}\left(\frac{1-e^R}{1-e^{RT}}\right) = \left(\frac{1-e^R}{(1-e^{RT})^2}\right)R$$

Therefore

$$\frac{\partial C_T}{\partial T} = S \times \left(\frac{1-e^R}{1-e^{RT}}\right) + C_{VT} \times \frac{\partial}{\partial T}\left(\frac{1-e^R}{1-e^{RT}}\right) \tag{17}$$

in which is expressed in known quantities from equation (14), similarly

$$\frac{\partial C_T}{\partial T_1} = \frac{\partial C_{VT}}{\partial T_1} \times \left(\frac{1-e^R}{1-e^{RT}}\right) \tag{18}$$

solution of equation (17) and (18) will yield optimal T and T_1.

OPTIMAL SOLUTION

By direct search approach it can be shown that given by (15) is convex in feasible domain of T and T_1. Therefore the optimum value of T and T_1 minimizing C_T can be obtained by simultaneously solving equations $\frac{\partial C_T}{\partial T_1} = 0$ and $\frac{\partial C_T}{\partial T} = 0$. The expression for the total cost involves higher order exponential terms, it is not easy to evaluate the Hessians in closed form, to conclude about its positive definiteness directly, and thus it is not trivial to see whether the total cost function is convex.

Case II T<M (i.e., after depletion payment)

The deterioration cost C_D^i, carrying cost, C_H^i and the backorder cost C_B^i per cycle are the same as in the equation (8), (9) and (12) respectively. The interest paid P_T^i per cycle is equal to zero when T_1 <M because the supplier can pay in full at the end of permissible delay, M. The interest earned per cycle is the interest earned during the positive inventory period plus the interest earned from the cash invested during the time period (T_1, M) after the inventory is exhausted at time I_T^i, it is given by

$$I_T^i = \int_0^T c_o I_e(t) t(a+bt)dt + (e^{i_e(M-T_1)} - 1)\int_0^{T_1} c_0 t(a+bt)dt$$

$$= \frac{caT_1 e^{(R+i_e)T_1}}{(R+i_e)} - ca\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^2}\right) + cbT_1^2 \frac{e^{(R+i_e)T_1}}{R+i_e} - cb\left(\frac{2T_1 e^{(R+i_e)T_1}}{(R+i_e)^2}\right) + 2cb\left(\frac{e^{(R+i_e)T_1}-1}{(R+i_e)^3}\right)$$

$$-\frac{caT_1 e^{(R-r)T_1}}{(R-r)} + ca\left(\frac{e^{(R-r)T_1}-1}{(R-r)^2}\right) - cbT_1^2 \frac{e^{(R-r)T_1}}{R-r} + cb\left(\frac{2T_1 e^{(R-r)T_1}}{(R-r)^2}\right) - 2cb\left(\frac{e^{(R-r)T_1}-1}{(R-r)^3}\right)$$

$$(e^{i_e(M-T_1)} - 1)cb\left(\frac{T_1^2 e^{RT_1}}{R} - \frac{2T_1 e^{RT_1}}{R^2} + \frac{2(e^{RT_1}-1)}{R^3}\right) \quad (19)$$

Incorporating the modification of I_T^i in equation (19) and $P_T^i = 0$ into equation (13) because of the changes in assumption for case II, value in equation has changed from that in equation (14). The solution structure for the total annual cost remains the same as in equation (15). So a similar solution structure may be applied for the optimal solution of T_1 and T as it was done earlier from multiple cycles per year in equations (15)-(18).

CONCLUSION

In this paper we have considered the concept of permissible delay in payment under the effect of inflation and time value of money with time dependent demand rate. We have considered two cases with respect to depletion time T_1 which is either greater than or less than permissible delay. Thus this paper will help inventory managers in deciding their stock of inventory having time dependent demand Numerical illustration is also given

NUMERICAL ILLUSTRATIONS

For A=Rs. 500, T = 6months, M = 2 months, T_1 = 4 months, I_p = .20, I_e =.18, R=.1, c = Rs. 10, c_b = Rs. 20 a = .500, b = 10 , I =.12 gives C_T = Rs. 39377.6

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