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INVENTORY MODEL FOR DECAYING ITEMS WITH TIME VALUE OF MONEY UNDER PERMISSIBLE DELAY IN PAYMENTS

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ABSTRACT

In classical Inventory EOQ model it is assumed that payment against an order is made immediately after receiving the item'. But in reality, the customers are offered a permissible delay in payments for settling the account. Usually no interest is charged if the outstanding amount is settled within the permitted fixed settlement period. Beyond this period, interest is charged. During the period before the account has to be settled, the customer can sell the items and continue to accumulate revenue and earn interest instead of paying off the overdraft which is necessary if the supplier requires settlement of the account immediately after replenishment. Therefore, it makes economic sense for the customer to delay the settlement of the replenishment account up to the last moment of the permissible period allowed by the supplier. This paper presents an inventory model to determine an optimal ordering policy for deteriorating items having exponential demand rate with delay in payments permitted by the supplier.

Key words: Inventory, delay

INTRODUCTION

Classical deterministic inventory models consider the demand rate to be either constant or time-dependent but independent of the stock status. However, for certain types of consumer goods (e.g., fruits, vegetables, donuts and other) of inventory, the demand rate may be influenced by the stock level. It has been noted by marketing researchers and practitioners that an increase in a product’s shelf space usually has a positive impact on the sales of that product and it is usually observed that a large pile of goods on shelf in a supermarket will lead the customer to buy more, this occurs because of its visibility, popularity or variety and then generate higher demand. In such a case, the demand rate is no longer a constant, but it depends on the stock level. This phenomenon is termed as ‘stock dependent consumption rate’. In general, ‘stock dependent consumption rate’ consists of two kinds. One is that the consumption rate is a function of order quantity (initial stock level) and the other is that the consumption rate is a function of inventory level at any instant of time.

The consumption rate may go up or down with the on-hand stock level. These phenomena attract many marketing researchers to investigate inventory models related to stock-level. Conversely, low stocks of certain baked goods (e.g., donuts) might raise the perception that they are not fresh. Therefore, demand is often time and inventory-level dependent.

This paper strives; an inventory model for deteriorating items with multi variate demand rate under inflationary environment. We have taken a more realistic demand rate that depends on two factors, one is time, and the second is the stock level available. The stock level in itself obviously gets depleted due to the customer’s demand. As a result, what we witness here is a circle in which the customer’s demand is being influenced by the level of stocks available, while the stock levels are getting depleted due to the customer’s demands. This assumption takes the customer’s interests as well as the market forces into account. The demand rate is such that as the inventory level increases, it helps to increase the demand for the inventory under consideration. While as the time passes, demand is depends upon the various factors. The competitive nature of the market has been accounted for by taking permissible delay in payments into consideration. Finally, the results have been illustrated with the help of numerical examples. Also, the effects of changes of different parameters are studied graphically.

REVIEW OF LITERATURE

Ghare and Shrader (1963) proposed an economic order quantity model for items having a constant rate of deterioration horizon. Covert and Philip (1973) developed a model with Weibull distribution deterioration. Sarma (1987) discussed a deterministic order level inventory model for deteriorating items with two storage facility. Datta and Pal (1988) developed a model with variable rate of deterioration. A stochastic inventory model when delay in payments are permissible was considered by Shah (1993). Hwang and Shinn (1997) included the pricing strategy to the model, and developed the optimal price and lot-sizing for a retailer under the condition of permissible delay in payments. A deterministic order level inventory model for deteriorating items with two storage facilities was proposed by Benkherouf (1997). Bhunia and Maiti (1998) discussed a model for deteriorating items with linear trend in demand. Liao et al. (2000) proposed an inventory model with deteriorating items under inflation when a delay in payment is permissible. Huang et al. (2001) presented an inventory model for deteriorating items with linear trend under the condition of permissible delay in payments. Kar et al. (2001) proposed deterministic inventory model with linear trend in demand. Zhou and Yang (2005) presented a two-warehouse model with stock level dependent demand rate. Shah (2006) considered an inventory model for deteriorating items and time value of money under permissible delay in payments during a finite planning horizon. Soni et al. (2006) discussed an EOQ model for progressive payment scheme under discounted cash flow. Jaggi et al. (2006) proposed a model for deteriorating items with inflation induced demand. Ouyang et al. (2006) presented an inventory model for deteriorating items under permissible delay in payments. Chung and Huang (2007) investigated models for deteriorating items with limited storage facility. Chang et al. (2008) reviewed trade credit models. Wu et al. (2009) proposed an optimal payment time for deteriorating items under inflation and permissible delay in payments. Lee and Hsu (2009) discussed two-warehouse production model with time dependent demand rate. Liang and Zhou (2011) discussed a two-warehouse inventory model for deteriorating items under conditionally permissible delay in payment. Ghoreishi et al. (2015) developed an economic ordering policy for non-instantaneous deteriorating items with selling price and inflation induced demand under permissible delay.

Chang (2004) proposed an inventory model under a situation in which the supplier has provided a permissible delay in payments to the purchaser if the ordering quantity is greater than or equal to a predetermined quantity. Shortage was not allowed and the effect of the inflation rate, deterioration rate and delay in payments were discussed as well. Models for ameliorating / deteriorating items with time-varying demand pattern over a finite planning horizon were proposed by Moon et al. (2005). The effects of inflation and time value of money were also taken into account. An inventory model for deteriorating items with stock-dependent consumption rate with shortages was produced by Hou (2006). Model was developed under the effects of inflation and time discounting over a finite planning horizon. The results were discussed with a numerical example and particular cases of the model were discussed in brief. Sensitivity analysis of the optimal solution with respect to the parameters of the system was carried out.

Jolai et al. (2006) presented an optimization framework to derive optimal production over a fixed planning horizon for items with a stock-dependent demand rate under inflationary conditions. Deterioration rate was taken as two parameter Weibull distribution function of time. Shortages in inventory were allowed with a constant backlogging rate. Two-warehouse partial backlogging inventory models for deteriorating items were discussed by Yang (2006). The inflationary effect was considered in the models. Deterioration rates in both the warehouses were taken as constant. Some numerical examples for illustration were provided and sensitivity analysis on some parameters was made.

N. K. and Maiti, M. (2005) presented the multi objective and single objective inventory models of stochastically deteriorating items are developed in which demand is a function of inventory level and selling price of the commodity. Wu et al. (2006) proposed an optimal replenishment policy for non-instantaneous deteriorating items with stock-dependent demand and partial backlogging. Panda et al. (2007) considered an EOQ model with ramptype demand and Weibull distribution deterioration. Sana and Chaudhuri (2008) formulated the retailer's profit maximizing strategy. Increasing deterministic demands were also discussed.

Jaggi et al. (2007) presented the optimal inventory replenishment policy for deteriorating items under inflationary conditions using a discounted cash flow (DCF) approach over a finite time horizon. Shortages in inventory were allowed and completely backlogged and demand rate was assumed to be a function of inflation. Optimal solution for the proposed model was derived and the comprehensive sensitivity analysis has also been performed to observe the effects of deterioration and inflation on the optimal inventory replenishment policies. Two stage inventory problems over finite time horizon under inflation and time value of money was discussed by Dey et al. (2008).

Jamal et al. (2000) presented optimal payment time for a retailer under permitted delay of payment by the wholesaler. The wholesaler allowed a permissible credit period to pay the dues without paying any interest for the retailer. In the study, a retailer model was considered with a constant rate of deterioration. The inventory replenishment policy for deteriorating items under permissible delay in payments was presented by Chung (2000). The problem was illustrated numerically. An inventory model for initial-stock-dependent consumption rate was suggested by Liao et al. (2000). Shortages were not allowed. The effects of inflation rate, deterioration rate, initial stock-dependent consumption rate and delay in payments were discussed.

ASSUMPTIONS AND NOTATIONS:

The mathematical models of the two warehouse inventory problems are based on the following assumptions and notations:

Assumptions:

- The inventory system involves a single type of items.
- Demand rate is dependent on time and stock level.
- Deterioration rate is taken as Kt.
- Shortages are not permitted.
- The replenishment rate is instantaneous.
- Lead time is neglected.
- Permissible delay in payment to the supplier by the retailer is considered. The supplier offers different discount rates of price at different delay periods.
- Planning horizon is infinite.
- Inflation and time value of money is considered.

Notations:

- $D = a + bt + cI(t)$ Time and Stock dependent demand
- C_O = Ordering cost
- C_h = holding cost per unit time, excluding interest charges
- C_P = purchasing cost which depends on the delay period and supplier's offers
- p = selling price per unit
- M = permissible delay period
- M_i = i^{th} permissible delay period in settling the amount
- $_i$ = discount rate (in %) of purchasing cost at i-th permissible delay period.
- i_e = rate of interest which can be gained due to credit balance
- i_c = rate of interest charged for financing inventory

- T = length of replenishment
- $AP_1(T, M_i)$ = average profit of the system for $T \geq M_i$
- $AP_2(T, M_i)$ = average profit of the system for $T \leq M_i$
- Q_0 = Initial lot size

MODEL FORMULATION AND SOLUTION

The cycle starts with initial lot size Q_0 and ends with zero inventory at time t=T. Then the differential equation governing the transition of the system is given by

$$\frac{dI(t)}{dt} = -Kt - (a + bt + cI(t)), \qquad 0 \leq t \leq T \qquad \text{... (1)}$$

With boundary condition I(0) = Q_0

The purchasing cost at different delay periods are

$$C_P = \begin{cases} C_r(1-\delta_1), M = M_1 \\ C_r(1-\delta_2), M = M_2 \\ C_r(1-\delta_3), M = M_3 \\ \infty, M > M_3 \end{cases}$$

Where C_r = maximum retail price per unit.

And M_i (i=1,2,3) = decision point in settling the account to the supplier at which supplier offers δ % discount to the retailer.

Now two cases may occur:

1. When $T \geq M$
2. When $T < M$

Case 1: when $T \geq M$

Solving the equation (1), we get

$$\frac{dI(t)}{dt} + KtI(t) = -(a + bt + cI(t))$$

Using the boundary condition I(0) = Q_0, we get

c = Q_0

Therefore the solution of equation (1) is

$$I(t) = \left\{ Q_0 - at - \frac{(a+b)}{2}t^2 - \left(\frac{aK}{2} + b\right)\frac{t^3}{3} - \frac{bK}{8}t^4 \right\} e^{-t-Kt^2/2} \qquad 0 \leq t \leq T \qquad \text{... (2)}$$

In this case it is assumed that that the replenishment cycle T is larger than the credit period M.

The holding cost, excluding interest charges is

$$HC = C_h \int_0^T I(t)e^{-rt}dt$$

$$\begin{aligned} \mathrm{HC} = \mathrm{C_h} \Bigg[& \left\{ \mathrm{Q_0 T} - \frac{\mathrm{a}}{2}\mathrm{T}^2 - \frac{(\mathrm{a}+\mathrm{b})}{6}\mathrm{T}^3 - \left(\frac{\mathrm{aK}}{2} + \mathrm{b}\right)\frac{\mathrm{T}^4}{12} - \frac{\mathrm{bK}}{40}\mathrm{T}^5 \right\} \\ & -(1+\mathrm{r})\left\{ \frac{\mathrm{Q_0}}{2}\mathrm{T}^2 - \frac{\mathrm{a}}{3}\mathrm{T}^3 - \frac{(\mathrm{a}+\mathrm{b})}{8}\mathrm{T}^4 - \left(\frac{\mathrm{aK}}{2} + \mathrm{b}\right)\frac{\mathrm{T}^5}{15} - \frac{\mathrm{bK}}{48}\mathrm{T}^6 \right\} \\ & -\frac{\mathrm{K}}{2}\left\{ \frac{\mathrm{Q_0}}{3}\mathrm{T}^3 - \frac{\mathrm{a}}{4}\mathrm{T}^4 - \frac{(\mathrm{a}+\mathrm{b})}{10}\mathrm{T}^5 - \left(\frac{\mathrm{aK}}{2} + \mathrm{b}\right)\frac{\mathrm{T}^6}{18} - \frac{\mathrm{bK}}{56}\mathrm{T}^7 \right\} \Bigg] \end{aligned} \qquad \text{... (3)}$$

The cost of financing inventory during time span [M,T] is

$$FC = i_c C_P \int_M^T I(t) e^{-r(M+t)} dt$$

$$\begin{aligned} FC = i_c C_P \Bigg[& (1-rM)\left\{Q_0 T - \frac{a}{2}T^2 - \frac{(a+b)}{6}T^3 - \left(\frac{aK}{2}+b\right)\frac{T^4}{12} - \frac{bK}{40}T^5\right\} \\ & -(1+r)\left\{\frac{Q_0}{2}T^2 - \frac{a}{3}T^3 - \frac{(a+b)}{8}T^4 - \left(\frac{aK}{2}+b\right)\frac{T^5}{15} - \frac{bK}{48}T^6\right\} \\ & -\frac{K}{2}\left\{\frac{Q_0}{3}T^3 - \frac{a}{4}T^4 - \frac{(a+b)}{10}T^5 - \left(\frac{aK}{2}+b\right)\frac{T^6}{18} - \frac{bK}{56}T^7\right\} \\ & -(1-rM)\left\{Q_0 M - \frac{a}{2}M^2 - \frac{(a+b)}{6}M^3 - \left(\frac{aK}{2}+b\right)\frac{M^4}{12} - \frac{bK}{40}M^5\right\}. \\ & +(1+r)\left\{\frac{Q_0}{2}M^2 - \frac{a}{3}M^3 - \frac{(a+b)}{8}M^4 - \left(\frac{aK}{2}+b\right)\frac{M^5}{15} - \frac{bK}{48}M^6\right\} \\ & +\frac{K}{2}\left\{\frac{Q_0}{3}M^3 - \frac{a}{4}M^4 - \frac{(a+b)}{10}M^5 - \left(\frac{aK}{2}+b\right)\frac{M^6}{18} - \frac{bK}{56}M^7\right\}\Bigg] \end{aligned} \quad \text{... (4)}$$

Opportunity gain due to credit balance during time span [0,M] is

$$Opp.Gain = i_e p \int_0^M (M-t)(a+bt+cI(t)) e^{-rt} dt$$

$$Opp.Cost = i_e p \left[(a+bM)\frac{e^{-rM}}{r^2} - 2b\frac{e^{-rM}}{r^3} + \frac{aM}{r} - \frac{(a-bM)}{r^2} + \frac{2b}{r^3} \right] \quad \text{... (5)}$$

Therefore, the total cost is given by

TC_{1i}=Purchasing Cost +holding cost +ordering cost +interest charged-interest earned for M϶{M_1,M_2,M_3}

$$TAC_{1i} = \frac{1}{T} TC_{1i} \quad \text{... (6)}$$

Case 2 when T < M

In this case, credit period is larger than the replenishment cycle consequently cost of financing inventory is zero. The holding cost, excluding interest charges is

$$HC = C_h \int_0^T I(t) e^{-rt} dt$$

$$\begin{aligned} HC = C_h \Bigg[& \left\{ Q_0 T - \left(\frac{a}{2}T^2 + \frac{b}{6}T^3 + \frac{aK}{24}T^4 + \frac{bK}{40}T^5\right)\right\} \\ & - r\left\{\frac{Q_0}{2}T^2 - \left(\frac{a}{3}T^3 + \frac{b}{8}T^4 + \frac{aK}{30}T^5 + \frac{bK}{48}T^6\right)\right\} \\ & - \frac{K}{2}\left\{\frac{Q_0}{3}T^3 - \left(\frac{a}{4}T^4 + \frac{b}{10}T^5 + \frac{aK}{36}T^6 + \frac{bK}{56}T^7\right)\right\}\Bigg] \end{aligned} \quad \text{...(7)}$$

Opportunity gain due to credit balance during time span [0,M] is

$$Opp.Gain = i_e p \left[\int_0^T (T-t)(a+bt) e^{-rt} dt + \int_0^T (M-T)(a+bt) e^{-rt} dt \right]$$

$$= i_e p\left[\int_0^T \{aT + (bT - a)t - bt^2\} e^{-rt} dt + (M - T)\int_0^T \{a + bt\} e^{-rt} dt\right] \quad ..... (8)$$

Therefore the total cost during the time interval T is given by

TC_{2i}=Purchasing cost +holding cost +ordering cost-interest earned (Opp. cost)

$$TAC_{2i} = \frac{1}{T} TC_{2i} \quad ..... (9)$$

Now, our aim is to determine the optimal value of T and M such that TAC(T,M) is minimized where

$$TAC(T,M) = Inf.\begin{cases} TAC_{1i}(T,M), TAC_{2i}(T,M) \\ where, M\varepsilon(M_1, M_2, M_3) \end{cases} \quad ..... (10)$$

Special case:

Case 1 when there is no deterioration, i.e. K=0, then

$$I(t) = \left\{Q_0 - \left(at + \frac{b}{2}t^2\right)\right\}, \qquad 0 \le t \le T$$

$$\begin{aligned} FC = i_c C_P \Bigg[& \left\{Q_0 T - \left(\frac{a}{2}T^2 + \frac{b}{6}T^3\right)\right\} - rM\left\{Q_0 - \left(aT + \frac{b}{2}T^2\right)\right\} \\ & - \frac{K}{2}\left\{\frac{Q_0}{3}T^3 - \left(\frac{a}{4}T^4 + \frac{b}{10}T^5\right)\right\} - r\left\{\frac{Q_0}{2}T^2 - \left(\frac{a}{3}T^3 + \frac{b}{8}T^4\right)\right\} \\ & - \left\{Q_0 M - \left(\frac{a}{2}M^2 + \frac{b}{6}M^3\right)\right\} + rM\left\{Q_0 - \left(aM + \frac{b}{2}M^2\right)\right\} \\ & + \frac{K}{2}\left\{\frac{Q_0}{3}M^3 - \left(\frac{a}{4}M^4 + \frac{b}{10}M^5\right)\right\} + r\left\{\frac{Q_0}{2}M^2 - \left(\frac{a}{3}M^3 + \frac{b}{8}M^4\right)\right\} \Bigg] \end{aligned}$$

$$Opp.Cost = i_e p\left[(a + bM)\frac{e^{-rM}}{r^2} - 2b\frac{e^{-rM}}{r^3} + \frac{aM}{r} - \frac{(a - bM)}{r^2} + \frac{2b}{r^3}\right]$$

Case 2: when the demand rate is constant means b=0

$$I(t) = \left\{Q_0 - \left(at + \frac{aK}{6}t^3\right)\right\} e^{-Kt^2/2} \qquad 0 \le t \le T$$

$$\begin{aligned} HC = C_h \Bigg[& \left\{Q_0 T - \left(\frac{a}{2}T^2 + \frac{aK}{24}T^4\right)\right\} - r\left\{\frac{Q_0}{2}T^2 - \left(\frac{a}{3}T^3 + \frac{aK}{30}T^5\right)\right\} \\ & - \frac{K}{2}\left\{\frac{Q_0}{3}T^3 - \left(\frac{a}{4}T^4 + \frac{aK}{36}T^6\right)\right\} \Bigg] \end{aligned}$$

$$Opp.Cost = i_e p\left[a\frac{e^{-rM}}{r^2} + \frac{aM}{r} - \frac{a}{r^2}\right]$$

Table 1: Variation in TC with the variation in a

a	T	TC(10^5)
70	37643	6.5247
80	34.1886	6.1436
90	33.9981	7245
100	32.0002	2681
110	32.8266	8957
120	30.1724	3541
130	29610	4.5232

Table 2: Variation in TC with the variation in b

b	T	TAC(10^5)
30	2235	10.2954
35	28.1254	10.1118
40	30.4457	9.9725
45	33.1896	8.1829
50	33.7832	7.2681
55	34.1457	7.0075
60	34.8485	6.3221
65	39517	6.1882
70	36.1725	6.0914
75	38.8954	3236

Table 3: Variation in TC with the variation in C_h

C_h	T	TAC(10^5)
0.020	18.7241	8954
0.025	29154	2.3112
0.030	21892	2.7776
0.035	27.2431	3.8154
0.040	29.8561	4.1112
0.045	31452	4.5772
0.050	32.0002	2681
0.055	33.5231	6.3314
0.060	34.1272	6.7821
0.065	34139	7.1957

Table 4: Variation in TC with the variation in K

K	T	TAC(10^5)
0.0008	32.8081	4.5417
0.0009	32.8081	4.9857
0.0010	32.8081	2681
0.0015	32.8081	6.8934
0.0020	32.8081	6.9572
0.0025	32.8081	7.2231
0.0030	32.8081	7.8573
0.0035	32.8081	9.4315
0.0040	32.8081	10.5473
0.0045	32.8081	11892

CONCLUSION

In this paper we developed a model with supplier's trade offer of credit and price discount the purchase of stock. The model considered the both, deterioration effect and time discounting. Generally, supplier offer different price discount on purchase of items of retailer at different delay periods. Suppliers allow maximum delay period, after which they will not take a risk of getting back money from retailers or any other loss of profit. Constant deterioration is not a viable concept; hence, we have considered an inventory with deterioration increasing with time.

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