Effect of Inflation and Variable Holding Cost on Life Time Inventory Model with Multi Variable Demand and Lost Sales

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Abstract: This paper analyses an inventory model for life time declining item with variable carrying rate and multi variable demand rate. In this model, the consumption rate depending on selling price as well as displayed stock and when the shortage occurs only on selling price of the manufactured article. Moreover, in this model the deterioration is taken time dependent, which is non-instantaneous in nature. In this study we also consider a very realistic concept of variable carrying rate in which the carrying rate per unit period to be a function of the time used up in storage. This model is firm for minimizing the average total rate per unit period under the effect of inflation and time value of money. Numerical examples are used to illustrate the wished-for model and a sensitivity analysis is passed out to study the effect of different constraints.

Keywords: Variable holding cost, Inflation, Partially backlogging, Multi variable demand, Life time.

I. INTRODUCTION

The traditional parameters such as carrying cost, setup cost and demands rate in most EOQ models generally are assumed to be fixed. Consequently, these models have a lot of dissimilarity with real life situations. This issue has encouraged lots of researchers to amend and update the inventory models to match real world conditions. The assumption holding cost is always fixed is not true in general and thus to represents real-life situations, this paper carrying rate is supposed to be varying function of time. In the previous decade, whenever the idea of variable carrying rate received devotion of several researchers., Rastogi et al. (2017) analyzed an inventory model for deteriorating items with price dependent demand, partial backlogging, having time varying carrying cost. Sharmila and Uthayakumar (2018) developed the two warehouse deterministic inventory model used for deteriorating objects with time erratic carrying rate. Inflation is a concept diligently linked to epoch. Inflation is usually connected with quickly rising costs which decrease the purchase of money that varies depending on the time it depends to a great extent. A small amount of inflation can affect the economy positively. It is a thought of everyone that inflation is not good, but it is not necessarily so. Inflation affects different people in different ways. Buzacott (1975) was the master who is credited with the exploration of an unknown alley when he first put forward his study on inflation. Datta et al. (1991) made an try to investigate the influence of inflation and time-value of money on an inventory model with linear consumption rate.

In life, the deterioration of object comes to be a mutual factor. Normally, we describe deterioration as decay or loss of objects, such as fruits, foods, vegetables, etc. Extremely volatile liquids like alcohol, turpentine, gasoline, radioactive materials, etc., deteriorate due to evaporation though kept in store. The deterioration is one of the essential aspects in inventory analysis. However, the deteriorating products are not useable. So we cannot ignore this fact and its consequence to inventory analysis. Ghare and Schrader (1963) first established an EOQ model over not infinite planning horizon having a constant rate of demand and not varying rate of deterioration. Singh and Singh (2011) considered the imperfect production process with exponential consumption rate, deterioration under inflation. Singh and Sharma (2016) consequent an inventory model for deteriorating goods with accidental demand and not deflation. Sharma et al. (2018) considered an inventory model for deteriorating objects with end date and time erratic carrying rate.

Furthermore, the phenomenon of shortages in an inventory situation is the real world position. In most of the old-style inventory model it is supposed that during the stock-out period, shortages are also completely backordered or completely lost. Several customers are willing to wait for backorder and others would turn to buy from other sellers. Singh et al. (2007) have discussed delicate inventory model with quadratic demand and shortage allowed with partial backlogging rate. Singh et al. (2012) developed an inventory model with rework and flexibility under allowable shortage.

The problem of inventory has become an important issue that established sizeable consideration in inventory models with demand rates stock-dependent. Gupta and Vrat (1986) first developed an inventory model for the consumption rates displayed stock-dependent. Sarker et al. (1997) developed a model for order level lot size with consideration of inventory level dependent consumption and deterioration. In the last few years, the inventory models under the condition of stock dependent demand studied by several researchers.

Lee and Dye (2012) worked on an inventory model considering consumption rate stock dependent. Singh et al. (2016) derived an inventory model for declining items having stock dependent demand with permissible shortages. Mashud et al. (2018) considered a non-instantaneous inventory model having different deterioration rates with price as well as dependent demand. In the presented work, we have presumed that the inventory model is described multi variable demand rate, non-instantaneous deteriorations and partially backlogged shortages.
Moreover, in this model inflation taken and the deterioration is taken time dependent, then this deterioration rate increases.

Variable carrying cost models assume the carrying rate per unit per period to be a function of the period used up in storage. The numerical example and sensitivity analysis are presented to show this study. The rest of the paper is planned as follows. Section 2 starts with notations and assumptions. Section 3 describes the mathematical model. The solution procedure is outlined in section 4. Section 5 provides numerical results, sensitivity analysis and managerial insights. As a final point the conclusions and future research directions are drained in section 6.

II. ASSUMPTIONS AND NOTATIONS

A. Assumptions
1. The time-value of money and inflation are measured.
2. Carrying rate is linearly increasing time function i.e. \( h(t) = u + vt \) where \( u, v > 0 \).
3. Replenishment rate is life time and not lead-time.
4. Demand rate \( D(p) = m - np \) when \( I(t) \in [0, t_1] \)
\[\begin{align*}
  & m - np + cI(t) \quad \text{when } I(t) \in [t_1, t_3], \\
  & p(m - np) \quad \text{when } I(t) \in [t_3, T]
\end{align*}\]
where \( m, n > 0 \) and \( c > 0 \).

i.e., when \( I(t) \geq 0 \) consumption is dependent on price in the interval \([0,t_1]\) and on selling price as well as displayed stock in the interval \([t_1,t_3]\) and when \( I(t)<0 \) consumption is dependent only on price.
5. The planning horizon of the inventory situation is not finite.
6. The product has not considered deterioration in interval \([0,t_1]\). Deterioration arises in the time interval \([t_1,t_2]\) and \([t_2,t_3]\) at two different time varying rates \( \theta_1 \) and \( \theta_2 \), where \( 0 < \theta_1 << 1 \) and \( 0 < \theta_2 << 1 \).
7. Shortages are taken and these are partially backlogged with a backlogging rate \( \rho \), where \( 0 < \rho < 1 \).

B. Notations

In addition, the following nomenclatures are used in the paper development*.

| Symbol | Description |
|--------|-------------|
| \( O \) | Ordering cost per order |
| \( C_p \) | Purchasing cost per unit |
| \( C_d \) | The rate of deterioration |
| \( C_l \) | Lost sales rate |
| \( C_h \) | Shortage rate |
| \( \theta_1, \theta_2 \) | Constant deterioration rates. |
| \( K \) | Maximum number of units in stock per cycle |
| \( R \) | Unit maximum units in shortage level |
| \( \rho \) | Selling price $/unit |
| \( I_1(t) \) | The level of inventory when the deterioration of product is not start at any time \( t \in [0,t_1] \). |
| \( I_2(t) \) | The level of inventory when the deterioration of product starts at any time \( t \in [t_1,t_2] \). |
| \( I_3(t) \) | The level of inventory when the deterioration of product starts at any time \( t \in [t_2,t_3] \). |
| \( I_4(t) \) | The level of inventory at any time \( t \in [t_3,T] \) with the shortage of product |
| \( u \) | Initial holding cost |

III. MATHEMATICAL FORMULATION

This model it is supposed the consumption function is dependent on price during the interval \([0,t_1]\) and dependent on price and stock in the interval \([t_1,t_2]\) and in shortage time \([t_2,T]\). The deterioration is considered as non-instantaneous, which means that when the item in retailer’s house after any time deterioration is likely to begin with a constant rate for certain period, then due to the effect of time and different parameters the deterioration will increase. Then after shortages appear and it is partially backlogged. Initially a creativity purchased \((K+R)\) units of stocks. This stock reduces to meet up the customer demands and deterioration. After time \( t_1 \) the deterioration will increase with a rate \( \theta_1 \), but due to time effect this deterioration will decrease to rate after time \( t_2 \). At the end of period \( t_3 \), inventory level depletes up to zero. Again, during time interval \([t_3,T]\) shortages stars occurring and at \( T \) there are maximum shortages, due to partial backordering some sales are lost. The status of the inventory at any instant of time is governed by the following differential equation.

\[
\begin{align*}
  V & = \text{rate of increase in holding cost} \\
  P & = \text{rate of partially backlogging} \\
  \rho & = \text{inflation rate, } 0 \leq r < 1 \\
  W & = \text{Initially inventory level at } t_1, \text{ where } 0 < W < K \\
  t_1 & = \text{Time at which the level of inventory reaches to } W \text{ where } 0 < W < K \text{ and deterioration start with time dependent rate } \theta_1 \\
  t_2 & = \text{Time at which the level of inventory decreases due to deterioration rate } \theta_2 \\
  t_3 & = \text{The time of inventory level when inventory reaches to zero} \\
  T & = \text{replenishment cycle’s length} \\
  \text{TUC} & = \text{Total unit cost}
\end{align*}
\]
\[ I_s(t) + \theta_s t I_s(t) = -(m - np + c I_s(t)) \quad t_2 \leq t \leq t_3 \quad (3) \]

With \( I_s(t_3) = 0 \)

\[ I_s(t) = -\rho(m - np) \ , \ t_3 \leq t \leq T \quad (4) \]

With \( I_s(t_3) = 0, I_s(T) = R \)

Solution of above differential equations:

From eq. (1) we have,

\[ I_s(t) = (m - np)(t_1 - t) \quad (5) \]

and \( W = (m - np) t_1 \)

From eq. (2) we have

\[ I_c(t) = (K - W) \left[ 1 + c(t_1 - t) + \frac{\theta_c (t_1 - t)^2}{2} \right] + (m - np) \]

\[ \left[ (t_1 - t) + \frac{c(t_1 - t)^2}{2} + \frac{\theta_c (t_1 - t)^2}{6} \right] e^{-\theta_c t} \quad (6) \]

From eq. (3) we have

\[ I_c(t) = (m - np) \left[ (t_1 - t) + \frac{c(t_1 - t)^2}{2} + \frac{\theta_c (t_1 - t)^2}{6} \right] e^{-\theta_c t} \quad (7) \]

Using continuity at the point \( t = t_2 \), it gives \( I_c(t_2) = I_s(t_2) \) i.e.

\[ K = W + (m - np) \left[ (t_1 - t_2) + \frac{c(t_1 - t_2)^2}{2} + \frac{\theta_c (t_1 - t_2)^2}{6} \right] e^{-\theta_c t_2} \]

\[ (m - np) \left[ (t_1 - t_2) + \frac{c(t_1 - t_2)^2}{2} + \frac{\theta_c (t_1 - t_2)^2}{6} \right] e^{-\theta_c t_2} \quad (9) \]

From eq. (4) we have

\[ I_s(t) = \rho(m - np)(t_3 - t) \quad (10) \]

The total cost per unit time

Ordering cost = O

The purchase cost (PC) = \( C_p(K+R) \)

The shortage cost

\[ SC = C_s \int_{t_2}^{t_3} I_s(t) e^{-\gamma t} \, dt \quad (11) \]

\[ SC = C_s \rho(m - np) \left[ \frac{c(t_1 - t)^2}{2} + \frac{r_c (t_1 - t)^2}{6} \right] e^{-\gamma t} \quad (12) \]

The inventory holding cost

\[ HC = (u + v) \left[ \int_{t_2}^{t_3} I_s(t) e^{-\gamma t} \, dt + \int_{t_2}^{t_3} I_c(t) e^{-\gamma t} \, dt + \int_{t_2}^{t_3} I_s(t) e^{-\gamma t} \, dt \right] \]

\[ HC = (u + v) \int_{t_2}^{t_3} I_s(t) e^{-\gamma t} \, dt + (m - np) \left[ \frac{3t_1^2 - r_1^2}{6} + \frac{3t_2^2 - r_2^2}{6} \right] + \frac{K - W}{r_1} \quad (13) \]

Deterioration cost

\[ DC = C_d \left[ \theta_d \int_{t_2}^{t_3} I_s(t) e^{-\gamma t} \, dt + \theta_d \int_{t_2}^{t_3} I_c(t) e^{-\gamma t} \, dt \right] \]
The convexity of the total cost function is obtained by the well-known Hessian matrix. Here, Hessian matrix of the total cost function is obtained by the following necessary and sufficient conditions:

\[
\frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T^2} = 0, \quad \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1^2} = 0, \\
\frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_2^2} = 0 \quad \text{and} \quad \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_3^2} = 0
\]

The convexity of the total cost function is obtained by the well-known Hessian matrix. Here, Hessian matrix of the total cost function

\[
H(T, t_1, t_2, t_3) = \begin{bmatrix}
    \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T^2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_1} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_3} \\
    \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_1} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1^2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1 \partial t_2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1 \partial t_3} \\
    \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1 \partial t_2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_2^2} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_2 \partial t_3} \\
    \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial T \partial t_3} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_1 \partial t_3} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_2 \partial t_3} & \frac{\partial^2 TC(T, t_1, t_2, t_3)}{\partial t_3^2}
\end{bmatrix}
\]

Where the principal minors of \(H(T, t_1, t_2, t_3)\) are \(|H_{11}| > 0, |H_{22}| > 0, |H_{33}| > 0\) and \(|H_{44}| > 0\), which are all positive. Therefore the total inventory cost is a convex function.

V. NUMERICAL EXAMPLE

To show the developed model, a numerical example is presented below with the following values of different parameters has been considered. Let us study the following values of different parameters as follows:

\[O = 300, \ m = 100, \ n = 0.54, \ p = 20, \ c = 0.2, \ C_p = 15, \ C_b = 10, \ u = 2, \ v = 0.7, \ C_k = 13, \ r = 0.075, \ \theta_1 = 0.03, \ \theta_2 = 0.01, p = 0.07, \ C_d = 1.5, W = 160 \text{respectively.}
\]

Solving the outlined problem provides following solutions:

\[TC = 718.655, \ K = 397.018, \ R = 24.458, \ T = 10.154
\]

\[t_1 = 3.943, t_2 = 6.621, t_3 = 6.622
\]
Convexity of total cost with respect to $t_1$ and $T$

Convexity of total cost with respect to $t_2$ and $T$

Convexity of total cost with respect to $t_2$ and $t_d$

Convexity of total cost with respect to $t_3$ and $T$

C. Sensitivity Analysis

Sensitivity analysis is showed on certain parameters in order to explore the effects that changes in those parameters have on the expected total profit per unit time and the economic lot size. All input parameters were not considered as the proposed inventory has numerous input parameters. The sensitivity analysis was only showed on ten input parameters, $u, v, C_p, C_b, C_L, c, p, \theta_1, r$ and $W$ respectively. The sensitivity analysis is carried out by variation each parameter by $+20\%, +10\%, -10\%$ and $-20\%$, taking one parameter at a time and other parameters are constant.

| Parameters | Change (%) | $t_1$  | $t_2$  | $t_3$  | $T$   | $K$   | $R$   | T.C   |
|------------|------------|--------|--------|--------|-------|-------|-------|-------|
| $u$        | $+20$      | 3.3    | 5.9    | 5.9    | 6.4   | 419   | .98   | 3.1   | 839   | .41   |
|            | $+10$      | 3.5    | 5.9    | 5.9    | 6.5   | 402   | .00   | 2.6   | 814   | .53   |
|            | $-10$      | 4.1    | 6.5    | 6.5    | 6.5   | 369   | .82   | 0     | 748   | .81   |
|            | $-20$      | 2.0    | 5.4    | 5.4    | 5.5   | 569   | .05   | 0.4   | 945   | .48   |
| $v$        | $+20$      | 3.7    | 6.4    | 6.4    | 6.4   | 405   | .52   | 0     | 688   | .23   |
|            | $+10$      | 3.2    | 6.1    | 6.2    | 6.3   | 451   | .47   | 0.7   | 754   | .72   |
|            | $-10$      | 3.9    | 6.3    | 6.3    | 7.0   | 369   | .05   | 5.1   | 821   | .18   |
|            | $-20$      | 3.5    | 5.8    | 5.8    | 6.1   | 368   | .51   | 1.9   | 885   | .87   |
| $C_p$      | $+20$      | 2.9    | 6.0    | 6.0    | 6.0   | 485   | .75   | 0.4   | 965   | .27   |
|            | $-10$      | 3.2    | 6.0    | 6.0    | 6.0   | 436   | .91   | 0     | 717   | .37   |

Retrieval Number: E6249018520/2020©BEIESP
DOI:10.35940/ijrte.E6249.018520

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication
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| \( C_b \) | \( +20\% \) | \( -20\% \) |
|---|---|---|
| \( C_b \) | 3.5 | 3.7 |
| | 3.9 | 3.7 |
| | 3.9 | 3.7 |
| \( C_p \) | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| \( \theta_1 \) | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| \( C_d \) | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| \( W \) | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| \( \Gamma \) | 1.3 | 1.3 |
| | 1.3 | 1.3 |
| | 1.3 | 1.3 |

D. Observation

1. In table 1, it is well-established that the parameter \( u \) decreases then the cycle time \( T \), \( t_1 \), \( t_2 \) and \( t_3 \) increases whenever the highest shortage level \( R \), the highest on hand stock level \( K \) and optimal total cost decreases. But it is also noticeable that the \( T \), \( t_1 \), \( t_2 \), \( t_3 \), \( K \), \( R \) and the optimal total cost at -20% parameter \( u \) keep abnormal behaviors.

2. In table 1, it is well-established that the demand parameter \( v \) decreases then the cycle time \( T \), \( t_1 \), \( t_2 \), \( t_3 \), \( R \) and \( K \) are first increasing and then decreasing, but the optimal total cost increases respectively. The highest shortage level \( R \) is insensitive with respect to \( v \) at +20%.

3. Table 1 implies that the purchase cost \( C_p \) decreases then \( T \), \( t_1 \), \( t_2 \), \( t_3 \), \( R \) and \( K \) and optimal total cost are first increasing and then decreasing and vice versa. But it is noticeable that the highest shortage level \( R \) is insensitive with respect to \( C_p \) at -10% and -20%.

4. We can also see that the shortage cost \( C_b \) decreases then \( t_1 \) and \( R \) increases whenever \( K \) decreases. Other parameters slightly increase or decrease with respect to \( C_b \).

5. In table 1, it is seen that the parameter lost sale cost \( C_d \) decreases then \( t_1 \), \( t_2 \), \( t_3 \) and total cost decreases whenever the highest shortage level \( R \) and the cycle time \( T \) increases respectively. But the highest on hand stock level \( K \) is oscillating with respect to \( C_d \).

6. While the parameter \( \theta_1 \) decreases, total average cost of the system declines as well as in table 1. Furthermore, the \( t_1 \), \( t_2 \), \( t_3 \) and \( K \) increases, respectively. The cycle time \( T \) and \( R \) both are oscillating.

7. While the deterioration cost \( C_d \) decreases then \( t_1 \) and \( K \) both are increasing from +20% to -10% as well as in table 1, but at -20% it decreases. Furthermore, the cycle time \( T \), \( t_2 \), \( t_3 \), \( R \) and the total average cost are slightly increasing or decreasing respectively.

8. Table 1 implies that due to decline in \( W \) the \( t_2 \), \( t_3 \) increases and the total cost decreases. The parameter \( W \) decreases then \( t_1 \) increases and \( K \) decreases from +20% to -10%, but \( t_1 \) decreases and \( K \) increases at -20%. Other parameters \( R \) and \( T \) both are oscillating.

9. Table 1 implies that \( t_2 \) and \( t_3 \) increases and the total cost decreases due to decline in inflation rate \( r \). The inflation rate \( r \) decreases, then \( t_1 \) decreases from +20% to -10%, but \( t_2 \) decreases at -20% respectively. Other parameter \( R \) and \( T \) both are showing alternate behaviors. Accordingly, \( t_1 \) of the system is not affected due to decrease in

VI. CONCLUSION

This research, an inventory model for life time deteriorating item with movable carrying rate in which the consumption function depending on selling price as well as displayed and when the shortage occurs on selling price only of the manufactured goods.
Moreover, in this model the deterioration is taken time dependent, which is non-instantaneous in nature. The amount to which inflation has precious the business world is clearly explained over the sensitivity analysis, wherever the effect of inflation is observably shown over the total optimal cost. To make the study close to reality holding cost assumed as variable function, which increases with time. A numerical example shows that optimize total average cost followed by convexity graph that minimize total average cost of the organization such as if the life time deteriorating period goes up then the total average cost of the system will deplete. In future research, this model can be extended by considering stochastic market demand rate and another area is allowable delay in payment.

ACKNOWLEDGMENT
I am indebted to the UGC, New Delhi, India, for providing financial help in the form of JRF (F.16.6-Dec. 2016/2017).

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