A TWO WAREHOUSE INVENTORY MODEL WITH TIME VARYING DEMAND AND PARTIAL BACKLOGGING UNDER INFLATIONARY ENVIRONMENT

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Abstract:
In today’s high competitive market there are so many reasons such as offered concession in bulk purchasing, high ordering quantity, seasonal demand and lead time, which force the retailer to buy more than its storage capacity. In these circumstances the retailer needs an extra space to store this extra ordered quantity known as rented warehouse. Here an inventory model has been developed for deteriorating items with time dependent demand, allowed shortages and partial backlogging with time value of money. The model is developed with two storage facility. The items are stored in rented warehouse only after the filling of owned warehouse. Numerical example and sensitivity analysis are also provided to illustrate the model.

Keywords: Inventory; Deterioration; Inflation; Time varying demand; Shortages; Partial backlogging

1. Introduction
It is generally seen in real life conditions that there are so many reasons due to which the retailer intense to buy more than the capacity of the warehouse. In such cases the retailer needs an extra space to store the extra ordered quantity. This additional space is termed as rented warehouse. Hartley (1976) was the first to introduce a two-warehouse model. Sarma (1983) developed a deterministic inventory model for optimum release rule with infinite replenishment rate and two levels of storage. Pakkala and Achary (1992) presented a deterministic inventory model for deteriorating items with two warehouses storage system and finite replenishment rate. Yang (2004) introduced an inventory model for deteriorating items with two-storage inventory system with shortages and time value of money. Wee et al. (2005) developed a two-storage inventory system with partial backlogging and weibull distribution deterioration under inflation. Yang (2006) considered a two-storage partial backlogging inventory models for deteriorating items under the rate of inflation. Singh et al. (2013) discussed an inventory model with imperfect quality items with effect of learning and inflation under two finite storage capacity. Tayal et al. (2014) introduced an inventory model for deteriorating products with space restriction. According to this model the quantity, extra from the storage capacity is returned to the supplier with a penalty cost. Rastogi et al. (2017) presented a two warehouse inventory model with price sensitive demand and deterioration under shortages.

To manage and control the inventory, for further procedure, which have deteriorating nature is very important. In last decades many researchers considered it and developed different inventory models. Ghare and Schrader (1963) were the first to introduce the deterioration in inventory modelling. Covert and Philip (1973) developed an inventory model with Weibull rate of deterioration. Chakraborty et al. (1998) extended this model with shortages and variable demand. Giri et al. (2003) came forward with economics order quantity model with Weibull rate of deterioration, ramp type demand rate and allowable shortages. Skouri et al. (2009) considered an inventory model for deteriorating items with ramp type demand rate and partial backlogging. Tayal et al. (2014) presented an inventory model for multi items with variable rate of deterioration, expiration date and allowable shortages. Further Tayal et al. (2015) developed an inventory model for deteriorating items with seasonal products and an option of an alternative market. Khurana et al. (2015) introduced a supply chain production inventory model for deteriorating product with stock dependent demand under inflationary environment and partial backlogging. Tayal et al. (2015) came forward with a production model for non-instantaneous deteriorating item with time dependent holding cost and exponential demand rate. Singh et al. (2016) discussed an inventory policy for deteriorating product with seasonal and stock level dependent demand with partial backlogging of shortages. Tayal et al. (2016) presented an integrated production inventory model for perishable products with trade credit period and preservation technology. Singh et al. (2016) came forward with an economic order quantity model for deteriorating products with preservation having stock
dependent demand and trade credit period. Rastogi et al. (2017) developed an EOQ policy with time dependent holding cost and partial backlogging under trade credit limit and cash discount policy. Pandey et al. (2017) considered an EOQ model with quantity incentive strategy for deteriorating items and partial backlogging. Khurana et al. (2018) developed an economic production quantity model for deteriorating product with variable demand rate and allowable shortages.

Inflation plays a very important role in the development of an inventory model. The models developed without considering the inflation in price misleads the results. Buzacott (1975) was the first to develop an inventory model as economic order quantities with inflation. Teng et al. (1999) considered a deterministic inventory model with shortages and deterioration for fluctuating demand under the inflationary environment to find out the economic lot size. Wee et al. (2005) introduced a two storage inventory model with partial backlogging during stock out and weibull rate of deterioration under inflation. Sarkar and Moon (2011) developed a production quantity model considering inflation in an imperfect production system. Tayal et al. (2014) presented an inventory model with two echelon supply chain for deteriorating items considering preservation technology investment.

2. Assumptions

The mathematical model for two warehouse inventory problem developed here with the following assumptions.

1. The model is developed for infinite time horizon.
2. Lead time is not considered in the development of this model.
3. The owned warehouse $W_1$ has a fix capacity to storage $W$ units while the rented warehouse has unlimited capacity.
4. The LIFO dispatching policy is used here.
5. The demand rate is an increasing function of time and is given by:
6. $D(t) = \alpha e^{\beta t}$
7. Shortages are allowed and partially backlogged.
8. The rate of backlogging is a waiting time dependent function and is given by:
9. $\theta(\eta) = (1 - \frac{\eta}{T})$
10. The rate of inflation is also considered here.

3. Notations

These following are the notations used throughout in the development of this model.

- $\eta$ waiting time up to the next replenishment
- $T$ replenishment cycle
- $W$ capacity of the owned warehouse
- $t_1$ the time at which inventory level in rented warehouse becomes zero
- $v$ the time at which inventory level in owned warehouse becomes zero
- $k$ deterioration parameter, $0 < k < 1$
- $c$ purchasing cost per unit
- $h_1$ holding cost per unit for warehouse $W_1$
- $h_2$ holding cost per unit for warehouse $W_2$
- $d_1$ deterioration cost per unit in warehouse $W_1$
- $d_2$ deterioration cost per unit in warehouse $W_2$
- $r$ inflation rate
- $s$ shortage cost per unit
- $l$ lost sale cost per unit
- $o$ ordering cost per unit

4. Mathematical Modeling

The inventory level behavior of the system has been shown in below mentioned figure (1). According to it at $t=0$, an inventory level of ‘$S$’ units enters in the system. After filling the owned warehouse the remaining quantity of $(S-W)$ units is transferred to rented warehouse. The LIFO (Last in first out) dispatching policy is used for the system. The inventory in owned warehouse is used only after the end of inventory in rented warehouse. In the duration $[0, t_1]$ the inventory decreases due to demand and deterioration and the inventory in owned warehouse decreases due to deterioration only. At time $t=t_1$, the inventory level of owned warehouse becomes zero and after this time, the inventory in owned warehouse depletes due to combined effect of demand and deterioration. At $t=v$, the inventory in owned warehouse also becomes zero and after this point shortages occur. The occurring shortages during $[v, T]$ are partially backlogged with time dependent rate of backlogging.

![Fig. 1: Inventory time graph for the system for two warehouses](image-url)
\[ \frac{dI_1(t)}{dt} = -kI_1(t) \quad 0 \leq t \leq t_1 \tag{1} \]
\[ \frac{dI_2(t)}{dt} = -\alpha e^b - kI_2(t) \quad t_1 \leq t \leq v \tag{2} \]
\[ \frac{dI_3(t)}{dt} = -\alpha e^b \quad v \leq t \leq T \tag{3} \]

For warehouse \( w_1 \):
\[ \frac{dI_1(t)}{dt} = -\alpha e^b - kI_1(t) \quad 0 \leq t \leq t_1 \tag{4} \]

With boundary conditions:
\[ I_{w_1}(0) = w, \quad I_{w_1}(v) = 0, \quad I_{w_1}(T) = 0 \]

The solutions of these equations are given by:

For warehouse \( w_1 \):
\[ I_{w_1}(t) = \alpha e^{-b} (v - t) \quad 0 \leq t \leq t_1 \tag{5} \]
\[ I_{w_1}(t) = \alpha [(v - t) + (t_1^2 - t^2)] e^{-b} t_1 \leq t \leq v \tag{6} \]
\[ I_{w_1}(t) = \alpha [(v - t) + (t_1^2 - t^2)] e^{-b} \quad v \leq t \leq T \tag{7} \]

For warehouse \( w_2 \):
\[ I_{w_2}(t) = \alpha (t_1 - t) + (t_1^2 - t^2) \left( \frac{\beta}{2} + \frac{k}{2} \right) e^{-b} \quad 0 \leq t \leq t_1 \tag{8} \]

By equating equations (5) & (6), we get:
\[ w = \alpha [(v - t_1) + (t_1^2 - t^2)] \tag{9} \]

Initial Inventory level \( Q_1 \) can be calculated by using equation (5) & (8)
\[ Q_1 = I_{w_1}(0) + I_{w_2}(0) \]
\[ Q_1 = \alpha (v + \frac{\beta}{2} v^2 + \frac{k}{2} v^2) \tag{10} \]

Backordered quantity due to stock out will be:
\[ Q_2 = \int_{0}^{v} \int_{t}^{T} \alpha e^b \theta(t) \, dt \, dt \]
\[ Q_2 = \int_{0}^{v} \int_{t}^{T} \alpha e^b \, dt \, dt \]
\[ Q_2 = \int_{0}^{v} \int_{t}^{T} \alpha e^b \, (1 - \frac{\theta}{T}) \, dt \, dt \]
\[ Q_2 = \int_{0}^{v} \int_{t}^{T} \alpha e^b \, (1 - \frac{\beta}{3} - \frac{k}{3}) \, dt \, dt \]
\[ Q_2 = \alpha \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \tag{11} \]

Purchasing Cost:
The inventory level is \( Q_1 \) at time \( t=0 \) and \( Q_2 \) is the backordered quantity from time \( t=v \) to \( t=T \). c denotes the purchasing cost per unit, the total purchasing cost will be:
\[ P.C. = c(Q_1 + Q_2) \]
\[ P.C. = \alpha c \left( (v + \frac{\beta}{2} v^2 + \frac{k}{2} v^2) + \frac{1}{3} \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \right) \tag{12} \]

Holding Cost:
It is a function that depends on time and it can be calculated for the time inventory exists in the system. The holding cost can be calculated as follows:

For warehouse \( w_1 \):
\[ H.C_1 = \int_{0}^{v} \int_{t}^{T} \alpha c e^b \, dt \, dt \]
\[ H.C_1 = \alpha c \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \tag{13} \]

For warehouse \( w_2 \):
\[ H.C_2 = \int_{v}^{T} \int_{t}^{T} \alpha c e^b \, dt \, dt \]
\[ H.C_2 = \alpha c \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \tag{14} \]

Deterioration Cost:
Deterioration cost can be calculated as follows:

For warehouse \( w_1 \):
\[ D.C_1 = \int_{0}^{v} \int_{t}^{T} \beta c e^b \, dt \, dt \]
\[ D.C_1 = \beta c \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \tag{15} \]

For warehouse \( w_2 \):
\[ D.C_2 = \int_{v}^{T} \int_{t}^{T} \beta c e^b \, dt \, dt \]
\[ D.C_2 = \beta c \left( \frac{T^2 - v^2}{2} + \frac{\beta}{3} (T^2 - v^2) \right) \tag{16} \]

Ordering Cost:
The ordering cost associated with per order is as follows:
\[ O.C. = o \tag{17} \]

Shortage Cost:
Shortages occur in the system at time \( t=v \) and are at its maximum at \( t=T \). Shortage cost can be calculated as follows:
\[ S.C. = \alpha \left( (1 - v)T - v + \frac{\beta}{2} v^2 + \frac{k}{2} v^2 \right) \tag{18} \]
Lost Sale Cost:
At the time of shortages some customer wait for the next stock and other make their purchases from another place and results in lost sale cost. It can be calculated as follows:

\[ L.S.C. = \frac{1}{T} \int_{0}^{T} a e^{-\beta t} \left( 1 - \left( T - \frac{t}{T} \right) e^{-(r+\alpha)T} \right) dt \]

\[ L.S.C. = \frac{1}{T} \left\{ \frac{\alpha T}{2} \left[ \frac{1}{2} - \frac{1}{2} e^{-\beta T} \right] + T \left( \frac{r}{6} - \frac{r \beta}{6} - \frac{\beta^2}{2} \right) + v^2 \left( \frac{\beta T}{2} \left[ \frac{1}{2} - \frac{3 \beta T}{2} \right] + T v \left( \frac{5r}{6} - \frac{r \beta}{3} \right) \right) \right\} \]

Total Average Cost:
Total average cost is the average of the sum of total associated cost.

\[ T.A.C. = \frac{1}{T} \left( P.C. + H.C. + D.C. + O.C. + S.C. + L.S.C. \right) \]

(20)

5. Numerical Example
We will calculate the optimal value of time for positive inventory in warehouse \( w_1 \), optimal value of time for positive inventory in warehouse \( w_2 \) and optimal value of total average cost with the help of a numerical example. The calculations are as follows:

\[ c = 25 \text{ rs/unit}, \alpha = 2000 \text{unit}, \beta = 0.03, k = 0.002, \]
\[ r = 0.08, h_1 = 3 \text{rs/unit}, h_2 = 3.5 \text{rs/unit}, d_1 = 26 \text{rs/unit}, \]
\[ d_2 = 26.5 \text{rs/unit}, s = 7 \text{rs/unit}, l = 8 \text{rs/unit}, o = 500 \text{rs} \]

After solving this model corresponding to these values we get:

\[ t_1 = 0.126566 \text{ year}, \quad v = 0.544893 \text{ year}, \]
\[ T = 0.650802 \text{ year}, \quad T.A.C. = 20117.6 \text{rs} \]

Fig 2: Convexity of the Total Average Cost function

6. Sensitivity Analysis
Taking one variable at a time and other variable unchanged, a sensitivity analysis is carried out with respect to different associated system parameter.

<table>
<thead>
<tr>
<th>Variation in ( \alpha )</th>
<th>( \alpha )</th>
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<th>T.A.C.</th>
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Fig 3: Variation in T.A.C. with respect to \( \alpha \)

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Fig 4: Variation in T.A.C. with respect to \( \beta \)
Table 3: Variation in total average cost with respect to deterioration parameter 'k':

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Fig 5: Variation in T.A.C. with respect to k

Table 4: Variation in total average cost with respect to inflation rate parameter 'r':

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Fig 6: Variation in T.A.C. with respect to r

Table 5: Variation in total average cost with respect to holding cost parameter 'h₁':

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Fig 7: Variation in T.A.C. with respect to h₁

Table 6: Variation in total average cost with respect to holding cost parameter 'h₂':

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Fig 8: Variation in T.A.C. with respect to h₂
7. Observations

A sensitivity analysis is carried out with respect to different system parameters taking one at a time and other variables unchanged.

1. From table (1) it is observed that as the value of demand parameter ‘α’ increases the values of ‘v’, t₁ and ‘T’ remains unchanged and the value of T.A.C. increases due to the increment in purchasing quantity.

2. Table (2) lists the variation in demand parameter ‘β’. It is observed from this table that with the increment in ‘β’, the values of ‘t₁’ and ‘v’ decreases slightly while the value of ‘T’ and total average cost increases.

3. With the help of table (3) one can conclude that with the increment in deterioration parameter ‘k’ the total average cost of the system decreases. The reason is the decrease in purchasing amount due to the increment in deterioration rate.

4. Table (4) states that as the value of inflation rate increases the time for positive inventory in rented warehouse decreases means a lower ordering quantity, which results in the lower total average cost for the system.

5. Table (5) lists the variation in holding cost parameter ‘h₁’. It is observed from this table that with the increment in h₁ the value of t₁ decreases and the total average cost of the system also decrease.

6. With the help of table (6) one can observe that with the increment in holding cost parameter ‘h₂’ the value of ‘v’, ‘t₁’ and ‘T’ remains unchanged and the total system cost increases.

8. Conclusion

Here in this paper an inventory model for deteriorating items has been developed with two warehouse facility in which one is owned warehouse and the other one is rented warehouse under the inflationary environment. The stock is transferred to rented warehouse only after the filling of owned warehouse. With the help of sensitivity analysis it is concluded that with the increased rate of deterioration the retailer has a tendency to buy a lower stock to reduce the cost of deterioration. A numerical example and sensitivity analysis with respect to different system parameters has been performed and the model is found to be quite suitable to meet the real life conditions. The convexity of the model has also shown with the help of numerical example. For further research scope this model can be extended with stock level and selling price dependent demand.

References


