Supply-chain two-warehouse inventory model for deteriorating items on exponential time function with shortage and partial backlogging in inflationary environment

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Abstract: In this paper, we have developed two-warehouse problem of supply chain system for deteriorating items, where demand is taken as the function of stock with the exponent function of time. The Practical situation of shortage also include due to the shortage of inventory occur so frequently in daily life in the inventory problem of supply chain system. Backlogging case of shortage is also taken into consideration to make the model more concerned with real life situation. Role of inflation cannot be avoided, so we have included an inflation factor in our model too. A sensitivity analysis is given by the suitable example. To justify our result graph between various parameters is also shown in analysis part. Keywords: term, term, term.

Keywords: Deterioration, Inflation, Stock Dependent Demand, Shortage, Partial Backlogging

1. Introduction

At the time when we talk about management of Inventory that time, we always discuss about the items which have nature of reducing its original value due to some factor. That factor called deterioration. Simply, it means every organization always deal with the product which lost their originality after a certain time interval. Such kind of product comes under the category of deterioration. Generally, every product has deteriorated nature, which cannot be stopped perfectly. The deterioration rate is treated as an uncontrollable variable usually. Wu et al. [26] talked about the model of non-instantaneous items which are deteriorating in nature. Where demand depends on the one variable and that variable is nothing but the available invent stock. Also backlogging rate introduce in this model. Wilson [27] formulated a problem of a methodical way of routing the stock to be controlled. Zhou et al [31] initiated a new variable in the model of production in which scheduling of strategy for deteriorating items has been discussed with time connected variable demand with the case partial lost sale.
Demand is the key factor of inventory management. Without the effective demand no business can run for a long run. Demand role becomes more effective when it depends on several variable, i.e. Demand of the product is based on many factors. Some of the time it may be price of product, some of the time it may be availability of stock of the product and some of the time many other factors too. Hence demand also can be depend on the stock.

Dye and Ouyang [2] formulated a concept of stock based demand in his model where the selling price is taken as a rate related to the un.preserved nature product under the time-dependent backlogging rate with partial case of customer return. Gayen and Pal [3] form a model of rented and owned warehouse been the focused of the model. In this inventory control model deteriorated nature items have been focused linked with the demand. In this model holding cost relates to items-based demand. Ghiami et al. [4] formulated a model of two-echelon system based on the deteriorating item under some capacity constraints and stock-based demand. Khanra et al. [8] explored a model of trade with credit environment has been explained with demand and shortage cases.

Lee and Dye [9] developed a model of inventory for deteriorating items linked with the suitable deterioration rate system. Patra and Ratha. [10] investigated a model under which some Policy for deteriorating items has been developed with the inflationary effect linked with the stock depend demand rate. Sarkar and Sarkar [15] focused on the improving the inventory situation under the partial case of backlogging liked with the time dependent deterioration and function of stock relying demand. Singh et al [16] explored two retailers ‘shops under the controllable system for deteriorated nature inventory connected with the shortages and items in the store-based demand under inflationary environment. Singh et al [17] focused on the policy of Replacement for the inventory of non-instantaneous nature linked with stock-based demand, back logging and inflation. Yadav et al. [29] lead the concept of fuzzy environment in the Inventory model of deteriorating items for two-warehouse case with stock dependent demand function of stock. Zhou et al. [31] developed a model of two warehouse inventory model for the items with the demand rate of stock-based function.

Gilding [5] presented the effect of inflation in the model where optimal ordering, inventory policies for the replenishment natured items has been under consideration. Sarkar et al. [20] explored a model in which price and time taken as a variable of a dependent demand function. Also effect of considerable reliability linked to the effect of inflation also been discussed to make this model effective and impressive. Sarkar et al. [21] proposed the model of a finite case of replacement rules and policy with an increasing pattern of demand and the effect of inflation on the total optimum cost. Patra and Rathore [10] create the concept of inflation in this model with inventory replacement policy for deteriorated nature items under a function of stock with the shortages. Singh and Rathore, [18] presented a 2-echelon based inventory model linked with the safety technology under the inflationary environment. Singh and Rathore, [19] focused on the optimal case of trade between a buyer and customer for deteriorating item model under the safety-based technology and inflation environment. Sharma et al. [22] explored a model of deteriorating items with the robust replacement case connected with the function of ramp type demand under the inflation and fuzzy environment. Sharma et al. [23] proposed a model for Deterministic Inventory model for deteriorating items under the demand function of Ramp-type based and inflationary environment.

In the current daily life scenario, each and every organization faced very odd and tough challenges to storing inventory for a long run so that good relation can be built with the customer for future connection for trade and purchasing aspect. Generally, the storage of any kind of inventory product
depends on the demand of product. If demand is high, then storage of product is needing more space to store with the constraints of the incomplete storage size of the owned warehouse. In that time rented warehouse needed to store extra product with high holding cost. Agrawal and Banerjee [1] explored the concept of warehouse of 2 type of space one is rented and other one is owned warehouse in this model with the function of ramp-type based demand connected with the and shortages. With backlogged case with customer return. Kumari et al. [6] developed the model in which concept of warehouse has been introduced to the deteriorated nature items linked with the rate of backlogging under the environments of tolerated delay in the payments parts. Kumar et al., [7] focused on a model of two warehouse inventory of deteriorated nature items with 3 variable dependent demand rate function and timely changed backlogging rate in the field of fuzzy environment situation. Sarma [11] investigated a model of deteriorating inventory under the two-storage housing facilities condition. Singh et al., [12] focused on the owned and rented warehouse management situation under inflationary environment with the shortage case of inventory. Singh and Rathore [13] developed a two-warehouse kind of inventory-based model with the non-instantaneous deteriorated items with the case of partial backlogging with the customer return and departure situation has been under consideration. Singh and Rather [14] developed the learning effect concept on the Two-warehouse based model with the concept of reverse logistic approach. By making it unusable product can be converted into the useable product. Also, a Two-warehouse problem of the inventory model with the backordering rate has been formulated by Wee et al., [25]. The effect of inflation with the Weibull’s distribution deterioration also considered in this model. Yang [30] investigated a model of two storage problem of warehouse under the partial backlogging-based inventory linked with inflationary environment.

In the present article, we have developed a two-storage house problem-based Inventory model with controllable constant deterioration Rate. In which demand rate taken as the function of stock and time variable. The shortages are permitted without partially backlogged. For the storage of items, two warehouse System is considered with limited storage Capacity at Owned Warehouse (OW) and unlimited Storage capacity at Rented Warehouse (RW). In Section 2, all the assumptions and notations used throughout the paper have been derived. In Section 3, the mathematical model for multivariate demands has been developed. In Section 4, the procedure of solving the problem has been presented. A numerical example has been given in Section 5. The sensitivity analysis results have been discussed in Section 6.

2. Assumptions and notations

2.1. Assumptions

i. The rate of Demand rate is exponentially and stock-dependent in nature and taken as the following form:

\[ D(t) = \begin{cases} 
  ae^{bt} + kI(t), & I(t) > 0 \\
  ae^{bt}, & I(t) < 0 
\end{cases} , a > 0, b > 0 \]

ii. The partially backlogged Shortages are allowed and where backlogging rate is given below

\[ B(t) = e^{-\delta t} , \delta > 0 \]
iii. Infinite Time horizon is considered.
iv. Lead time is zero with Infinite Replenishment rate is taken.
v. Warehouse (OW) has the limited space is allowed. On other hand the unlimited space area for 
rented warehouse has been permitted.
vi. The holding cost (h1) of the of Rented Warehouse is greater than the holding cost (h2) of Owned Warehouse.
vii. The charges for transportation and time between Rented Warehouse and Owned Warehouse are 
completely ignored.

2.2 Notations

The following notations are used in developing the inventory control model.

| Notation | Description |
|----------|-------------|
| i. A     | Ordering cost coefficient. |
| ii. h₁   | Coefficient of holding cost of Rented Warehouse (RW). |
| iii. h₂  | Coefficient holding cost of Owned Warehouse (OW). |
| iv. p    | Purchasing cost. |
| v. s     | Shortage cost |
| vi. l    | Coefficient of cost of lost sale. |
| vii. θ   | Constant rate of deterioration. |
| viii. R  | Inflation factor |
| ix. q₁   | Positive height of inventory of (RW) with \( I_1(t = 0) \) |
| x. q₂    | Positive height of inventory of (OW) with \( I_2(t=0) \) |
| xi. q₃   | The Negative height of inventory with \( I_3(t=T) \) |
| xii. Q   | Total order quantity of order. |
| xiii. T  | Total cycle time |
| xiv. t₁  | The Point of time where inventory height of rented Warehouse becomes zero. |
| xv. t₂   | The Point of time where which inventory height of Owned Warehouse becomes zero. |
| xvi. T   | The complete cycle length or phrase. |
xvii. $I_1(t)$ Height of inventory in rented warehouse between time intervals $[0, t_1]$.

xviii. $I_2(t)$ The height of inventory in owned warehouse between the time intervals $[0, t_1]$.

xix. $I_3(t)$ Height of inventory in O.W (owned warehouse) between the time intervals $[t_1, t_2]$.

xx. $I_4(t)$ Level of inventory in owned Warehouse between the time intervals $[t_2, T]$.

xxi. $TC$ The Total cost.

xxii. $TAC$ Present total Average cost.

xxiii. $PC$ Cost of purchasing.

xxiv. $HC$ Cost of holding of inventory.

xxv. $SC$ Cost of shortage of the inventory.

xxvi. $LC$ Cost of lost sale cost of inventory

3. Mathematical model formulation

The level of inventory at the point of time $t = 0$ is $q_1$ units which is stored in the rented warehouse and the remaining $q_2$ units are stored in owned warehouse. The level of inventory of reduce because of the demand and deterioration through the time interval $[0,t_1]$ and at $t = t_1$, it approaches the zero level. After time $t_1$, demand of items is filled by using the inventory of Owned Warehouse throughout time interval $[t_1,t_2]$. In the time interval $[t_2, T]$, shortages occurred and negative inventory level at time T approaches to $q_3$ unit due to the demand only.

![Inventory level with respect to time.](image-url)
The inventory depletion in RW is represented by

\[ \frac{dI_1}{dx} + \theta I_1 = -D(t) \quad [0, t_1] \]  \hspace{1cm} (1)  

The inventory depletion in Owned Warehouse is represented by

\[ \frac{dI_2}{dt} + \theta I_2 = 0 \quad , \quad [0, t_1] \]  \hspace{1cm} (2)  

\[ \frac{dI_3}{dt} + \theta I_3 = -D \quad , \quad [t_1, t_2] \]  \hspace{1cm} (3)  

\[ \frac{dI_4}{dt} = -D* B(t) \quad , \quad [t_2, T] \]  \hspace{1cm} (4)  

Solution of (1) with \( I_1(t = t_1) = 0 \) is given by equation (5)

\[ I_1(t) = \frac{a}{(\theta+k+b)} \left\{ p_1 e^{(\theta+k+b) t_1} \right\} \frac{p_1 e^{(\theta+k+b) t} - e^{k t}}{p_2 e^{(\theta+k+b) t_1} - e^{k t_1}} \right\}, \text{ where } p_1 = e^{(\theta+k+b)t_1}  \]  \hspace{1cm} (5)  

Solution of (2) with \( I_2(t = 0) = q_2 \) is given by equation (6)

\[ I_2(t) = e^{-\theta t} q_2 \]  \hspace{1cm} (6)  

Solution of (3) with \( I_3(t = t_2) = 0 \) is given by equation (7)

\[ I_3(t) = \frac{a}{(\theta+k+b)} \left\{ p_2 e^{(\theta+k+b) t} - e^{b t} \right\}, \text{ where } p_2 = e^{(\theta+k+b)t_2}  \]  \hspace{1cm} (7)  

Solution of (4) with \( I_4(t = t_2) = 0 \) is given by equation (8)

\[ I_4(t) = \frac{a}{(b-\delta)} \left\{ p_3 - e^{-(b-\delta)t} \right\}, \text{ where } p_3 = e^{(b-\delta)t_2} \]  \hspace{1cm} (8)  

Positive inventory level of rented warehouse with \( I_1(t = 0) = q_1 \) & equation (1) is given by

\[ q_1 = \frac{a}{(\theta+k+b)} \left\{ e^{(\theta+k+b)t_1} - 1 \right\} \]  

Negative inventory level with \( I_4(t = T) = -q_3 \) & equation (8) is given by
\[
q_3 = \frac{a}{(b - \delta)} \left\{ e^{(b - \delta)T} - e^{(b - \delta)T_2} \right\}
\]

Calculation for costs

1. Ordering cost = A

2. Purchasing cost = \( C_o \left[ q_1 + q_2 + q_3 \right] \)

\[
= \left[ \frac{a}{(\theta + k + b)} \left\{ e^{(\theta + k + b)T} - e^{(\theta + k + b)T_1} \right\} + q_1 + \frac{a}{(b - \delta)} \left\{ e^{(b - \delta)T} - e^{(b - \delta)T_2} \right\} \right]
\]

3. Shortage cost (CS) = \(-C_s \int_{T_2}^{T} I_4 \times e^{-Rt} dt\)

\[
= -C_s \times \frac{a}{(b - \delta)} \times \left\{ p_2 \left( e^{B_2} - e^{B} \right) \left\{ e^{(R - \delta)T} - e^{(R - \delta)T_2} \right\} \right\}
\]

4. Lost sales cost (LSC) = \( C_L \int_{T_2}^{T} \left( 1 - B(t) \right) \times Demand \times e^{-Rt} dt\)

\[
= C_L \times a \times \left\{ \frac{1}{(b - R)} \left\{ e^{(R)T} - e^{(R)T_2} \right\} \right\}
\]

5. Holding cost (HC) = \( \left[ \left( h_1 \right) \int_{0}^{h} I_1(t) e^{-Rt} dt + \left( h_2 \right) \int_{0}^{h} I_2(t) e^{-Rt} dt + \left( h_3 \right) \int_{0}^{h} I_3(t) e^{-Rt} dt \right] \)

\[
= h_1 \times \left\{ p_1 \left( \frac{1}{(\theta + k + R)} \right) \left[ 1 - e^{\theta + k + R} \right] \right\} \times e^{-(q + R)T_1} = h_2 \times \left\{ q_2 \left( \frac{1}{(\theta + k + R)} \right) \left[ 1 - e^{\theta + k + R} \right] \right\} \times e^{-(q + R)T_2} \]

Total cost = \[\text{Ordering cost} + \text{Purchasing cost} + \text{Holding cost} + \text{Deterioration cost} - \text{Shortage cost} + \text{Lost sales cost}\]
Total Average cost = \frac{1}{T} \left[ \text{Ordering cost} + \text{Purchasing Cost} + \text{Holding cost} + \text{Deterioration cost} - \text{Shortage cost} + \text{Lost sales cost} \right] \quad (15)

4. Optimal solution procedure

In this objective function has two variables are discussed, In order to obtain the optimal values of \( t \) and \( T \), the following method is used:

Step 1 Find \( \frac{\partial TAC}{\partial t} \) and \( \frac{\partial TAC}{\partial T} \)

Step 2 Let \( t^* \) and \( T^* \) be the values satisfying the equations \( \frac{\partial TAC}{\partial t} = 0 \) and \( \frac{\partial TAC}{\partial T} = 0 \)

\[ \begin{align*}
    \left( \frac{\partial^2 TAC}{\partial t^2} \right)_{(t^*,T^*)} & > 0 \quad \left( \frac{\partial^2 TAC}{\partial t \partial T} \right)_{(t^*,T^*)} > 0 \\
    \left( \frac{\partial^3 TAC}{\partial T^2} \right)_{(t^*,T^*)} & > 0
\end{align*} \]

5. Numerical Example

We consider the following parametric values for given parameters.

\[
A=100, C_1 = 2, C_2 = 3, C_3 = 0.3, a = 30, b = 0.5, K = 3, R = 0.01, \\
q_1 = 15, \theta = 0.01, h_1 = 0.8, h_2 = 0.1, \delta = 3
\]

We obtain the optimal values of the decision variable are \( t^* = 0.643742, T^* = 0.748977 \), and minimum total cost \( TAC^* = 118.956 \)
6. Sensitive Analysis
After the sensitivity analysis in the model, we have obtained the following results:

Table 1. Variation between various parameters with respect to ‘$h_1$’.

| $h_1$ | $t^*$ | $T^*$ | TAC$^*$ |
|-------|-------|-------|--------|
| 0.6   | 0.6798| 0.697448| 113.903 |
| 0.7   | 0.6611| 0.724639| 116.583 |
| **0.8** | **0.6437** | **0.7489** | **118.956** |
| 0.9   | 0.62744| 0.7709 | 121.075 |
| 1     | 0.6121| 0.7907 | 122.983 |

Figure 2. Convexity of TAC with respect to $T$ and $t^*_1$.

Figure 3. Changes in TAC$^*$ versus ‘$h_1$’.
Table 2. Variation between various parameters with respect to $'h_2'$.

| $h_2$ | $t^*$ | $T^*$ | $TAC^*$ |
|-------|-------|-------|---------|
| -     | 0.653038 | 0.653035 | 109.256 |
| 0.1   | 0.6488   | 0.70015  | 114.293 |
| 0.2   | 2.07034  | 0.7489   | 118.956 |
| 0.3   | 0.6322   | 0.840255 | 127.409 |

Figure 4. Changes in $TAC^*$ versus $'h_2'$.

Table 3. Variation between various parameters with respect to $'b'$.

| $b$   | $t^*$  | $T^*$  | $TAC^*$ |
|-------|--------|--------|---------|
| 0.3   | 0.61588 | 1.12899 | 122.013 |
| 0.4   | 0.6294  | 0.9096  | 121.946 |
| 0.5   | 2.07034 | 0.7489  | 118.956 |
| 0.6   | 0.6507  | 0.65074 | 112.759 |
| 0.7   | 0.6413  | 0.6413  | 104.967 |

Figure 5. Changes in $TAC^*$ versus $'b'$.

Table 4. Variation between various parameters with respect to $'a'$.

| $A$ | $t^*$  | $T^*$  | $TAC^*$ |
|-----|--------|--------|---------|
| 28  | 0.6498 | 0.7831 | 113.885 |
| 29  | 0.646709 | 0.765786 | 116.451 |
| 30  | 2.07034 | 0.7489  | 118.956 |
| 31  | 0.6409  | 0.7327  | 121.04  |
| 32  | 0.6382  | 0.7170  | 123.786 |

Figure 6. Changes in $TAC^*$ versus $'a'$.
Table 5. Variation between various parameters with respect to ‘A’.

| A | t' | T | TAC* |
|---|---|---|---|
| 80 | 0.604037 | 0.604037 | 88.072 |
| 90 | 0.6347 | 0.63478 | 104.21 |
| 100 | **0.6437** | **0.7489** | **118.956** |
| 110 | 0.6443 | 0.883102 | 131.218 |
| 120 | 0.6459 | 1.00279 | 141.825 |

Table 6. Variation between various parameters with respect to ‘C_S’.

| C_S | t | T* | TAC* |
|---|---|---|---|
| 1 | 0.643375 | 0.7613 | 119.281 |
| 1.5 | 0.64357 | 0.7551 | 119.121 |
| 2 | **0.6437** | **0.7489** | **118.956** |
| 2.5 | 0.6438 | 0.7427 | 118.78 |
| 3 | 0.644015 | 0.7364 | 118.611 |

Figure 7. Changes in TAC* versus ‘A’.

Figure 8. Changes in TAC* versus ‘C_S’.

7. Result

After the sensitivity analysis in the model, we have obtained the following results:

i. With an increases/decreases in the parameter C_S, t* increases/decreases, T* decreases/ increases and total cost TAC* decreases/increases respectively.

ii. With an increases/decreases in parameter a, t* increases/decreases, T* increases/ decreases and total cost TAC* increases/decreases respectively.

iii. With an increases/decreases in parameter a, t* decrease/increase, T* decreases/ increases and total cost TAC* increases/decreases respectively.

iv. With an increases/decreases in parameter b, t* decreases/increases, T* decreases/ increases and total cost TAC* decreases/increases respectively.
v. With an increase/decrease in parameter $h_2$, $t^*$ decreases/increases, $T^*$ increases/decreases and total cost $TAC^*$ increases/decreases respectively.

8. Conclusion

In this model, we have found the optimum value of total variable cost under some assumption. In which inflating effects the inventory problem and play a crucial effect with important role. Shortage with partial backlogging has been taken which give our model realistic approach connected with daily life problem with storage of items. In this end we have shown sensitivity analysis with appropriate example.

We can extend this result of this paper by taking different backlogging rate like constant and time dependent. Also, we can extend our demand by taking different form of demand and Linear holding case in this model for making new paper for extension of current paper too.

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