DETERIORATING INVENTORY MODEL IN DEMAND DECLINING MARKET UNDER INFLATION WHEN SUPPLIER CREDITS LINKED TO ORDER QUANTITY

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ABSTRACT

In this article, an inventory model is developed when supplier offers the retailer a credit period to settle the account, if the retailer orders a large quantity. The proposed study is meant for demand declining market. Shortages are not allowed and the effect of inflation is incorporated. The units in inventory are subject to constant rate of deterioration. The total cost is minimized for deteriorating items in demand declining market under inflation when the supplier offers a credit period to the retailer if the order quantity is greater than or equal to a pre – specified quantity. An easy – to – use algorithm is exhibited to find the optimal order quantity and the replenishment time. The mathematical formulation is explored by a numerical example. The sensitivity analysis of parameters on the optimal solution is carried out.

KEY WORDS: Inventory, inflation, trade credit, deterioration.

MSC : 90B05

1. INTRODUCTION

The classical economic order quantity model is derived under the assumption that the demand of the product is constant. However, the demand of seasonal goods, weather selected garments, blood during riots, accidents, etc. decreases after the particular phase is over. Another stringent assumption of the classical EOQ is that the retailer settles the accounts for the items as soon as items are received in his inventory system. In practice, the supplier offers a permissible credit period to the retailer if the outstanding amount is paid within the allowable fixed settlement period and the order quantity is large. The credit period is treated as a promotional tool to attract more customers. It can be expressed as a kind of price discount because paying later indirectly reduces

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The most of the above cited researchers have not considered influence of the inflation on inventory policy. However, from a financial point of view, an inventory represents a capital investment and must compete with other assets for a firm’s limited capital funds. (Chang(2004)). Buzacott(1975), Bierman and Thomas(1977) and Mishra(1979) discussed the inventory decisions under an inflationary condition for the EOQ model. One can read Brahmbhatt(1982), Chandra and Bahner(1985), Datta and Pal(1991) and their references.

In this paper, an attempt is made to formulate inventory model in demand declining market under inflation when a supplier offers a permissible delay of payments for a large order that is greater than or equal to the pre – specified quantity $Q_d$. It is assumed that if the order is less than $Q_d$, then the retailer must settle the account for the items received immediately. An easy – to – use algorithm is given to decide optimal order quantity and replenishment time. The numerical example is provided to support the working rules for the optimal solution. The sensitivity analysis is carried out to study the effect of parameters on the optimal solution.

2. ASSUMPTIONS AND NOTATIONS

The following notations and assumptions are used in the development of the model.

2.1 Notations

- $H$: the length of finite planning horizon
- $R(t)$: The demand rate where a ($a > 0$) is fixed demand and, $b$ Denotes rate of change of demand. $a > b$ and $0 < b < 1$
- $I$: the inventory carrying charge fraction per annum excluding interest charges
- $r$: Constant rate of inflation per unit time where $0 \leq r < 1$
- $P(t)$: $Pe^{rt}$; the selling price per unit at time $t$, where $P$ is the unit Selling price at $t = 0$.
- $C(t)$: $Ce^{rt}$; the purchase cost per unit at time $t$, where $C$ is the unit Purchase cost at $t = 0$.
- $A(t)$: $Ae^{rt}$; the ordering cost per order at time $t$, where $A$ is the ordering Cost at $t = 0$.
- $M$: The allowable credit to period in settling the account.
- $I_c$: The interest charged per $ for un-sold stock per annum by the supplier.
- $I_e$: The interest earned per $ per annum.
- $Q$: The order quantity (a decision variable)
- $Q_d$: The minimum order quantity pre – specified by the supplier at which the delay in payment is permissible.
- $T_d$: The time length at which $Q_d$ – units are depleted to zero.
\( \theta \)  
- The constant deterioration rate, where \( 0 \leq \theta \leq 1 \)

\( I(t) \)  
- The inventory level at any instant of time \( t \), \( 0 \leq t \leq T \).

\( T \)  
- The cycle time (a decision variable)

\( K(T) \)  
- The total cost of an inventory system during the planning horizon

The cost of an inventory system is the sum of
(a) Ordering cost; \( OC \)
(b) Purchase cost; \( PC \)
(c) Inventory holding cost excluding interest charged; \( IHC \)
(d) Interest charges payable for unsold stock after the credit period \( M \); \( IC \) and minus
(e) interest earned from the sales revenue during the credit period; \( IE \).

2.2. Assumptions

1. The inventory system under considerations deals with a single item.
2. The demand is partially constant and partially decreases with time.
3. The inflation rate is constant.
4. Shortages are not allowed and the lead – time is zero.
5. The planning horizon is finite.
6. The dues for the items procured must be made immediately if the order quantity is less than \( dQ \).

However, if the order quantity is greater than or equal to \( dQ \), then the delay in payment up to \( M \) is allowed. During this credit period, the generated sales revenue is deposited in an interest bearing account. At the end of the delay period, the retailer can settle the account and after that supplier charges interest on the unsold stock in the inventory system.

3. MATHEMATICAL MODEL

The retailer can make \( n \) – replenishments after every \( T \) – time units during the planning horizon \( H \). Thus, \( H = nT \) where \( n \) is an integer. The inventory level depletes due to demand and the deterioration of units. This rate of change of inventory level is governed by the differential equation.

\[
\frac{dI(t)}{dt} + \theta I(t) = -R(t) \quad ; \quad 0 \leq t \leq T
\]

(3.1)

With the boundary condition \( I(0) = Q \) and \( I(T) = 0 \). Hence the solution of (3.1) is given by

\[
I(t) = \frac{a}{\theta^2} \left[ \theta(1-bT)e^{\theta(T-t)} + be^{\theta(T-t)} - \theta(1-bT) - b \right] \quad ; \quad 0 \leq t \leq T
\]

(3.2)

and the order quantity is

\[
Q = I(0) = \frac{a}{\theta^2} \left[ \theta e^{\theta T} (1-bT) + b(e^{\theta T} - 1) - b \right]
\]

(3.3)

Using (3.3), the pre – specified \( Q_d \) units are given by
\[ Q_d = \frac{a}{\theta^r} \left[ \theta e^{\theta T} (1 - b T_d) + b(e^{\theta T} - 1) - b \right] \]  \hspace{1cm} (3.4)

Where \( T_d \) is the time at which \( Q_d \) units depletes to zero. The value of \( T_d \) is given by

\[ T_d = \frac{a \theta \pm \sqrt{a^2 \theta^2 - 4ab(\theta^2 Q - \theta a + b)}}{2ab} \]  \hspace{1cm} (3.5)

Obviously, \( Q < Q_d \) holds if and only if \( T < T_d \). Under the assumption that the lengths of time interval are equal, using (3.2), we have

\[ I(kt + t) = a \left[ T - t + b \left( t^2 - T^2 \right) \right] , \quad 0 \leq k \leq n - 1, \quad 0 \leq t \leq T \]  \hspace{1cm} (3.6)

The cost components of the total cost of an inventory system during planning horizon of length are as follows:

1. Ordering Cost
   \[ OC = A(0) + A(T) + A(2T) + .... + A((n-1)T) \]
   \[ = A \left( \frac{e^{\theta T} - 1}{e^{\theta T} - 1} \right) \]  \hspace{1cm} (3.7)

2. Purchase cost
   \[ PC = \left[ C(0) + C(T) + C(2T) + .... + C((n-1)T) \right] Q \]
   \[ = CQ \left( \frac{e^{\theta T} - 1}{e^{\theta T} - 1} \right) \]  \hspace{1cm} (3.8)

3. Inventory holding cost
   \[ IHC = h \sum_{k=0}^{n-1} C(kT) \int_0^T I(kt + t)dt \]
   \[ = \frac{Ca}{2\theta^r} \left( -2\theta - 2b - 2\theta T^2 + \theta^2 T^2 - 2\theta b T e^{\theta T} + 2b e^{\theta T} \right) \left( \frac{e^{\theta T} - 1}{e^{\theta T} - 1} \right) \]  \hspace{1cm} (3.9)

Regarding interest charges and earned, the following four cases are possible depending on the lengths of \( T, T_d \) and \( M \).

Since the cycle time \( T \) is less than \( T_d \), supplier will not facilitate the retailer for the trade credit to settle the account. The retailer will have to pay immediately for the units procured. This is the case of classical economic order quantity (EOQ). The interest charged for unsold items during finite planning horizon is

Case 1: \( 0 < T < T_d \) (Figure 1)
Inventory level

Figure: 1: 0 < T < Td

\[ IC_1 = I \sum_{k=0}^{n-1} C(kT) \left[ \int_0^T I(kT + t)dt \right] \]

\[ = \frac{CIa}{2\theta^2} \left( \frac{-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b}{e^{\theta T} - 1} \right) \]

Therefore, the total cost in \([0, H]\) is

\[ K_1(T) = OC + PC + IHHC + IC_1 \]

The necessary condition for \( K_1(T) \) to be minimum, is set derivative of \( K_1(T) \) with respect to \( T \) be zero;

\[ \left\{ \begin{array}{c}
-Are^{\theta T} (e^{\theta T} - 1) + Cae^{\theta T} (1 - bT)(e^{\theta T} - 1) - (h + I_c)Ca(1-bT)(1-e^{\theta T})(e^{\theta T} - 1) \\
\frac{Cae^{\theta T} (\theta b + \theta bTe^{\theta T} - \theta e^{\theta T} - be^{\theta T})(e^{\theta T} - 1)}{\theta^2 (e^{\theta T} - 1)^2} \\
- (h + I_c)Ca e^{\theta T} (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{\theta T} - 2\theta e^{\theta T} bT + 2be^{\theta T})(e^{\theta T} - 1) \\
\end{array} \right\} = 0 \]

Solve equation (3.12) for \( T = T_1 \) by mathematical software. The obtained \( T = T_1 \) will minimize total cost provided
\[
\frac{d^2 K_i}{d T^2} = \frac{A r^2 e^{rT} (e^{rH} - 1)(e^{rT} + 1)}{(e^{rT} - 1)^3} + \frac{C a r^2 e^{rT} (-\theta e^{rT} + \theta e^{rT} b T - be^{rT} + \theta + b)(e^{rH} - 1)}{\theta^2 (e^{rT} - 1)^2} \\
- \frac{2C a e^{rT} (-\theta e^{rT} + \theta e^{rT} b T - be^{rT} + \theta + b)(e^{rH} - 1)}{\theta^2 (e^{rT} - 1)^2} + \frac{2C a e^{rT} e^{rT} (b T - 1)(e^{rH} - 1)}{\theta^2 (e^{rT} - 1)^2} \\
- \frac{C a e^{rT} (\theta(b T - 1) + b)(e^{rH} - 1)}{\theta^2 (e^{rT} - 1)^2} + \frac{h C a (b + \theta e^{rT} - \theta e^{rT} b T - be^{rT})(e^{rH} - 1)}{\theta (e^{rT} - 1)} \\
+ \frac{2h C a e^{rT} (1-b T)(1-e^{rT})(e^{rH} - 1)}{\theta (e^{rT} - 1)^2} - \frac{I_L C a (b + \theta e^{rT} - \theta e^{rT} b T - e^{rT} b)(e^{rH} - 1)}{\theta (e^{rT} - 1)} \\
+ h C a e^{rT} (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{rT} - 2\theta e^{rT} b T + 2e^{rT} b)(e^{rH} - 1)(e^{rT} + 1)}{2\theta^3 (e^{rT} - 1)^3} \\
- \frac{I_L C a e^{rT} (-2\theta^2 + 2\theta^2 T b + 2\theta e^{rT} - 2\theta e^{rT} b T)(e^{rH} - 1)}{\theta^3 (e^{rT} - 1)^2} \\
+ \frac{I_L C a e^{rT} (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{rT} - 2\theta e^{rT} b T + 2e^{rT} b)(e^{rH} - 1)(e^{rT} + 1)}{2\theta^3 (e^{rT} - 1)^3} > 0
\]

(3.13)

Case 2: \(T_d \leq T < M\) (Figure 2)

Inventory Level

Since, \(T_d \leq T < M\) there is no interest charges. Interest earned during \([0, H]\) is

\[
IE_2 = \sum_{k=0}^{n-1} P(kT) \left[ \int_0^T R(t) dt + a(1 - bT)T(M - T) \right]
\]
Therefore, the total cost during \([0, H]\) is

\[
K_2(T) = OC + PC + IHC - IE_2
\]

The necessary and sufficient conditions for \(K_2(T)\) to be minimum at \(T = T_2\) are

\[
\begin{align*}
\frac{dK_2}{dT} &= - \frac{A\theta rT (e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} + \frac{C\theta rT (1 - bT)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} + \frac{I_2 rT (M - T)(1 - 2bT)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} \\
&\quad - \frac{C\theta rT (-\theta e^{\theta T} + \theta e^{\theta T} bT - be^{\theta T} + \theta + b)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} - \frac{hCa rT (1 - bT)(1 - e^{\theta T})(e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} \\
&\quad - \frac{hCae^T rT (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{\theta T} - 2\theta e^{\theta T} bT + 2be^{\theta T})(e^{\theta T} - 1)}{(e^{\theta T} - 1)^2} \\
&\quad - \frac{I_2 Par_e^T (T^2 (3 - 2bT) + 6(1 - bT)T(M - T))(e^{\theta T} - 1)}{6(e^{\theta T} - 1)^2} = 0
\end{align*}
\]

and

\[
\frac{d^2 K_2}{dT^2} = \frac{A\theta rT (e^{\theta T} - 1)(e^{\theta T} + 1)}{(e^{\theta T} - 1)^3} + \frac{C\theta rT (-\theta e^{\theta T} + \theta e^{\theta T} bT - be^{\theta T} + \theta + b)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} \\
&\quad - \frac{Ca e^T (\theta bT - 1) + b)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} - \frac{2Car_e^T (-\theta e^{\theta T} + \theta e^{\theta T} bT - be^{\theta T} + \theta + b)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} \\
&\quad + \frac{2Car_e^T e^{\theta T} (bT - 1)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} + \frac{hCa(\theta bT - 1 - e^{\theta T})(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} \\
&\quad + \frac{2hCae^T (1 - bT)(1 - e^{\theta T})(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} - \frac{2I_2 Par_e^T (2bT(M - T) - T)(e^{\theta T} - 1)}{(e^{\theta T} - 1)^3} \\
&\quad + \frac{hCar_e^T (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{\theta T} - 2\theta e^{\theta T} bT + 2be^{\theta T})(e^{\theta T} - 1)(e^{\theta T} + 1)}{20^2 (e^{\theta T} - 1)^3} \\
&\quad + \frac{I_2 Par_e^T (3T^2 - 2bT^3 + 6(1 - bT)T(M - T))(e^{\theta T} - 1)(e^{\theta T} + 1)}{6(e^{\theta T} - 1)^3} > 0
\]

Case 3: \(T_d \leq M \leq T\) (Figure 3)

Here, cycle time; \(T\) is greater than \(T_d\) and \(M\) both. Therefore, delay in payment is allowed. The interest earned in \([0, H]\) is
\[ IE_3 = I \sum_{k=0}^{n-1} P(kT) \left[ \int_0^M R(t)dt \right] \]

\[ = PIt \left( \frac{M^2}{2} - \frac{bM^3}{3} \right) \left( e^{\frac{H}{T}} - 1 \right) \]

(3.18)

And interest charged during \([0, H]\) is

\[ IC_3 = I \sum_{k=0}^{n-1} C(kT) \left[ \int_0^T I(kT+t)dt \right] \]

\[ = \frac{Cl}{\theta^3} \left[ -2\theta - 2\theta^2T + \theta^2T^2b + 2\theta e^{(\theta T^{-M})}(1-bT) + \left( \frac{e^{H}}{e^{T}} - 1 \right) \right] \]

(3.19)

Consequently, the total cost in \([0, H]\) is

\[ K_3(T) = OC + PC + IHC + IC_3 - IE_3 \]

(3.20)

Inventory level

Figure: 3: \(T_d \leq M \leq T\)

The total cost can be minimized for \(T = T_3\) (say) by setting

\[
\frac{dK_3}{dT} = \frac{-Ae^{\theta T} (e^{H/T} - 1)}{(e^{\theta T} - 1)^2} + \frac{Cae^{\theta T}(1-bT)(e^{H/T} - 1)}{(e^{\theta T} - 1)} - \frac{hCa(1-bT)(1-e^{\theta T})(e^{H/T} - 1)}{\theta(e^{\theta T} - 1)}
\]

\[
- \frac{hCar^2(-2\theta - 2\theta^2T + \theta^2T^2b + 2\theta e^{\theta T} - 2\theta e^{\theta T}bT + 2b e^{\theta T})(e^{H/T} - 1)}{\theta^3(e^{\theta T} - 1)^2}
\]
\[
\begin{align*}
I_c e^{rT} & \left(\frac{-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{\theta(T-M)}}{-2\theta e^{\theta(T-M)} b T + 2b e^{\theta(T-M)} + 2\theta^2 M - \theta^2 M^2 b + 2b M \theta}(e^{rH} - 1)\right) \\
& - \frac{I_c P a e^{rT} M^2 (2bM - 3)(e^{rH} - 1)}{6(e^{rT} - 1)^2} \\
& \frac{\theta^3 (e^{rT} - 1)^2}{6(e^{rT} - 1)^2} \\
\end{align*}
\]

(3.21)

Provided
\[
d^2 K_s = \frac{A r^2 e^{rT} (e^{rH} - 1)(e^{rT} + 1)}{(e^{rT} - 1)^2} + \frac{C a r^2 e^{rT} (-\theta e^{\theta T} + \theta e^{\theta T} b T - \theta e^{\theta T} + \theta + b)(e^{rH} - 1)}{(e^{rT} - 1)^3} \\
+ \frac{C a e^{\theta T} (\theta (bT - 1) + \theta)(e^{rH} - 1)}{(e^{rT} - 1)^2} - \frac{2 C a r^2 e^{2rT} (-\theta e^{\theta T} + \theta e^{\theta T} b T - \theta e^{\theta T} + \theta + b)(e^{rH} - 1)}{(e^{rT} - 1)^3} \\
+ \frac{2 C a e^{\theta T} (b + \theta)(e^{rH} - 1)}{(e^{rT} - 1)^3} + \frac{I_c c a (b + \theta e^{\theta(T-M)} - \theta e^{\theta(T-M)} T b - \theta e^{\theta(T-M)})(e^{rH} - 1)}{(e^{rT} - 1)^3} \\
+ \frac{h C a (b + \theta e^{\theta T} e^{\theta T} b T - \theta e^{\theta T})(e^{rH} - 1)}{(e^{rT} - 1)^2} + \frac{2 h C a e^{rT} (1 - b)(1 - e^{\theta T})(e^{rH} - 1)}{(e^{rT} - 1)^2} \\
+ \frac{h C a r^2 e^{rT} (-2\theta - 2b - 2\theta^2 T + \theta^2 T^2 b + 2\theta e^{\theta T} - 2\theta e^{\theta T} b T + 2e^{\theta T} b)(e^{rH} - 1)(e^{rT} + 1)}{2\theta^3 (e^{rT} - 1)^3} \\
+ \frac{2 I_c e^{rT} (1 - b)(1 - e^{\theta(T-M)})(e^{rH} - 1)}{(e^{rT} - 1)^3} \\
+ \frac{2 I_c P a M^2 (2bM - 3)r^2 e^{rT} (e^{rH} - 1)(e^{rT} + 1)}{6(e^{rT} - 1)^5} \\
\end{align*}
\]

(3.22)

Case 4: \(M \leq T_d \leq T\) (Figure 4)

Here, also cycle time is greater than or equal to both \(T_d\) and \(M\). and hence case 4 is similar to case 3, therefore, the total cost during \([0, H]\) is
\[
K_s(T) = OC + PC + IHC + IC_s - IE_s
\]

(3.23)

4. COMPUTATIONAL ALGORITHM
The retailer can decide optimal policy using following steps.

Step 1: Initialize all parameters.

Step 2: Compute $T = T_1$ using equation (3.12). If $T_1 < T_d$ then $K_1(T_1)$ is minimum; otherwise go to step 3.

Step 3: Compute $T = T_2$ using equation (3.16). If $T_2 < T < T_1$ then $K_2(T_2)$ is minimum; otherwise go to step 4.

Step 4: Compute $T = T_3$ using equation (3.21) and corresponding $K_3(T_3)$ is minimum; (Equivalently, $K_4(T_4)$ is minimum; otherwise go to step 4.)

Step 5: Stop.

5. NUMERICAL EXAMPLES

**Example: 1**
Consider $[H, a, b, h, I_c, I_c, r, C, P, M, Q_d, A, \theta] = [1, 50, 0.10, 2, 0.10, 0.06, 0.05, 20, 30, 30/365, 20, 120, 0.05]$ in proper units.

Following, algorithm defined in section 4, $T_1 = 0.3566 < T_d = 0.4042$ years. Hence case 1 is optimal decision. The minimum cost is $1722.78 and optimum purchase quantity is 17.67 units.

**Example: 2**
Consider $[H, a, b, h, I_c, I_c, r, C, P, M, Q_d, A, \theta] = [1, 50, 0.10, 2, 0.10, 0.06, 0.05, 20, 30, 120/365, 10, 120, 0.05]$ in proper units.
Then $T_d = 0.2010 < M = 0.3288$ years. Thus, case 2 is optimal decision policy. The optimal cycle time $T_2 = 0.3571$, minimum cost is $K_2(T_2) = 1691.53$ and purchase quantity is 17.69 units.

**Example: 3**

Consider

$$[H, a, b, h, I_c, I_r, r, C, P, M, Q_d, A, \theta] = [1, 50, 0.10, 2, 0.10, 0.06, 0.05, 20, 30, 30/365, 15, 120, 0.05]$$ in proper units.

Then $T_d = 0.3023 \text{ years} > M = 0.0822 \text{ years}$. From case 4, optimal cycle time $T_4$ is 0.3566 years, minimum cost $K_4(T_4)$ is $1714.62$. See Figure 5

![Figure 5 Convexity of total cost](image)

Next, we carry out variations in critical parameter to study effects on decision variable and total cost during $[0, H]$.

It is observed that increase in deterioration rate decreases cycle time and increases total cost of an inventory system during finite planning horizon. (Fig 6). The model is very sensitive to changes in the fixed demand ‘a’. (Fig 7) Increase in fixed demand increases total cost significantly and decreases cycle time. Increase in demand rate ‘b’ increases cycle time and decreases total cost of an inventory system. (Fig 8). The model is very sensitive to changes in ordering cost (Fig 9) and inflation rate (Fig 10). The total cost of inventory system decreases if supplier allows longer credit period. The decrease in total cost is because the retailer can earn more interest on the generated sales revenue.
<table>
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<th>Parameter</th>
<th>Cycle time $T$ (in years)</th>
<th>Total Cost $K(T)$ (in $)</th>
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<td>1706.69</td>
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<tr>
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6. CONCLUSIONS

In this study, optimal policy is derived for deteriorating items when the supplier provides a permissible delay in payments if ordered units are more than pre specified number by the supplier. The effect inflation is incorporated. The proposed model can be extended to a two – parameter Weibull distribution. It can be generalized to allow for shortages. The comparison of quantity discounts and trade credit is also an interesting future scope of research.

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REFERENCES


