Policy Decisions for a Price Dependent Demand Rate Inventory Model with Progressive Payments Scheme

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Abstract: Problem statement: In this proposed research, we developed an inventory model to formulate an optimal ordering policies for supplier who offers progressive permissible delay periods to the retailer to settle his/her account. We assumed that the annual demand rate as a decreasing function of price with constant rate of deterioration and time-varying holding cost. Shortages in inventory are allowed which is completely backlogged. Approach: The main objective of this study to frame an inventory model in real life situations. In this study, we introduced a new idea of trade credits, namely, the supplier charges the retailer progressive interest rates if the retailer prolongs its unpaid balance. By offering progressive interest rates to the retailers, a supplier, can secure competitive market advantage over the competitors and possibly improve market share profit. This study has two main purposes, first the mathematical model of an inventory system are establish under the above conditions and second demonstrate that the optimal solution not only exists but also feasible. We developed theoretical results to obtain the optimal replenishment interval by examine the explicit condition. An algorithm is given to find the flow of optimal ordering policy. Results: The results is illustrated with the help of numerical example using Mathematica software and the optimal solution of the problem is $Z(p, T_1) = 76.8586$ at $(p, T_1) = (0.952656, 0.128844)$. Conclusion: We proposed an algorithm to find the optimal ordering policy. A numerical study has been performed to observe the sensitivity of the effect of demand parameter changes.

Key words: Linear holding cost, progressive permissible delay, deterioration rate and shortages

INTRODUCTION

In the traditional Economic Order Quantity (EOQ) model, it is assumed that the retailer pays for the goods as soon as it is received by the system. However, in practice, the supplier offers a retailer a delay of fixed time period for setting the amount owed to him. Usually, there is no interest charge if the outstanding amount is paid within the credit period. However, if the payment is not paid in full by the end of the credit period, then interest is charged on the outstanding amount. Goyal (1985) developed an EOQ model under conditions of permissible delay in payments extended Goyal (1985) model by allowing shortages. Mandal and Phaujdar (1988) developed an inventory model by including interest earned from the sales revenue on the stoke remaining beyond the settlement period. Aggarwal and Jaggi (1995) extended Goyal’s model for deteriorating items because the loss due to deterioration cannot be ignored. Jamal et al. (1997) generalized the model to allow for shortage and deterioration. Liao et al. (2000); Chang and Dye (2001); Teng (2002); Teng et al. (2005) and Hwang and Shinn (1997) developed the model with permissible delay in period. Chang et al. (2010) Developed an Optimal replenishment policies for non-instantaneous deteriorating items with stock-dependent demand.

In the progressive trade credit period, retailer settles the outstanding amount by first credit period. Hence, the supplier does not charge any interest. Supplier charges an interest at rate $I_{c1}$ on the un-paid balance if retailer pays after first credit period but before second period offered by supplier to retailer. If retailer settles his amount after second credit period, then supplier charges to retailer an interest at rate $I_{c2}$ on un-paid balance ($I_{c1}<I_{c2}$). By assuming progressive trade credits to the retailer supplier can secure competitive market advantage and improve market share. Goyal et al. (2007) developed an inventory model with constant demand rate and deterioration rate under progressive payment scheme. Soni and Shah (2008) developed a model for stoke-dependent

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demand rate under progressive payment scheme. Singh et al. (2008) extended Soni and Shah (2008) model by allowing shortages and variable holding cost. This fact attracted a number of researchers to drive inventory models on price dependent demand rate patterns. Presented an inventory model for items having the demand rate is constant and variable deterioration rate under the trade credits. Some of the related works in this area are by Haley and Higgins (1973); Wee (1995); Chung and Tsai (2001); Teng (2002) and Teng et al. (2005).

In this study, we address the issues relating to progressive credit period relating to the retailer to settle his account. We developed a mathematical model when the demand rate, as a decreasing function of price and shortage which are fully backlogged with time varying holding cost. We assume that the supplier offers two progressive credit periods to the retailer to settle the account. The net profit is maximized by optimization technique. An algorithm is presented to derive the retailer’s optimal solution.

Fundamental assumptions and notations: The following assumptions are used to develop the model:

- The inventory system deals with the single item.
- Replenishment rate is finite.
- Shortage are allowed and completely backlogged.
- Lead time is zero.
- The annual demand, as a decreasing function of price; we get \( D(p) = \alpha p - \beta \), Where \( \alpha > 0 \) and \( \beta > 1 \). \( p \) denotes selling price of the item during the cycle time and a decision variable.
- If the retailer pays by M, then suppliers do not charge to the retailer. If the retailer pays after M and before N (N>M), he can keep the difference in the unit sale price and unit cost in an interest bearing account at the rate of \( I_e /unit/year \). During [M, N], the supplier charges the retailer an interest rate \( I_{c1} \) /unit/year. If the retailer pays after N, then supplier charges the retailer an interest rate of \( I_{c2} \) /unit/year (\( I_{c2} > I_{c1} \)) on unpaid balance.

The notations are as follows:

- \( h \) = Inventory holding cost/unit/year.
- \( P \) = Selling price/unit (a decision variable).
- \( S \) = Shortage cost/unit.
- \( C \) = Unit purchase cost with \( C < P \).
- \( M \) = First offered credit period in settling the account without any extra charge.
- \( N \) = Second permissible credit period in settling the account with interest rate \( I_{c2} \) on unpaid balance and \( N > M \).

Formulation of mathematical model Eq 1 and 2:

\[
\frac{d}{dt} Q(t) + \theta Q(t) = -D, \quad 0 \leq t \leq T_i
\]

(1)

\[
\frac{d}{dt} Q(t) = -D, \quad T_i \leq t \leq T
\]

(2)

And the order quantity is \( Q = \frac{D}{\theta} \left( e^{\theta T_i} - 1 \right) \) (5)

The cost components per unit time are as follows Eq. 6:

Ordering Cost (OC) = \( \frac{A}{T} \)

Inventory holding cost Eq. 7:

\[
HC = \frac{h}{T} \int_0^T Q(t) \, dt = \frac{h}{T} \int_0^T (e^{\theta T_i} - 1) \, dt + \frac{hD}{\theta T} \left[ e^{\theta T_i} - \theta T_i - 1 \right]
\]

(7)
The deterioration cost in the time interval \([0, T_1]\) is Eq. 8:
\[
DC = \frac{CD}{\theta T} \left[ e^{\theta T} - \theta T_1 - 1 \right]
\]

Shortage cost occurs during the period \([T_1, T]\) is given by Eq. 9 and 10:
\[
SC = \frac{S}{T} \int_{T_1}^{T} Q(t) \, dt = \frac{S}{T} \int_{T_1}^{T} D(T_1) \, dt
\]
\[
= \frac{SD}{T} \left[ \frac{T^2 + T_1^2}{2} - T_1 T \right]
\]

Gross revenue GR = \((pc) D(p)
\]

Regarding interest charged and interest earned based on the length of the cycle time \(T_1\), three cases arise:

Case 1: \(T_1 \leq M\), Case 2: \(M < T_1 < N\) and Case 3: \(T_1 \geq N\).

Case 1: \(T_1 \leq M\);

Here, Retailer sells \(Q\) units during \((0, T_1)\) and paying for \(CQ\) units in full to the supplier at time \(M \geq T_1\), so interest charges are zero, i.e. Eq. 11:
\[
IC_1 = 0
\]

Retailer deposits the revenue in an interest bearing account at the rate of \(le/\$ /\text{year}\). Therefore interest earned \(IE_1\), per year is Eq. 12:
\[
IE_1 = \frac{PI}{T} \left[ \int_0^{T_1} Q(t) \, dt + \int_{T_1}^{T} (M - T_1) \, dt \right]
\]
\[
= \frac{PI}{T} \left[ D + \left(\frac{D}{T^2} \left[ e^{\theta T} - \theta T_1 \frac{T}{2} - 1 \right] - \frac{SD}{T} \frac{T^2 + T_1^2}{2} - T_1 T \right) \right]
\]

To maximize the net profit at \(T_1 = T_1^*\) and \(p = p^*\), here \(T\) is fixed for one year planning horizon provided. The net profit Eq. 13:
\[
Z_1(p, T_1) = GR - OC - HC - DC - IC_1 + IE_1 - SC
\]
\[
= \left( P - C \right) D(p) - \frac{A}{T} - \frac{h D(p)}{\theta T} \left[ e^{\theta T} - \theta T_1 - 1 \right]
\]
\[
- \frac{CD(p) \left[ e^{\theta T} - \theta T_1 - 1 \right]}{\theta T} - \frac{SD(p)}{T} \left( \frac{T^2 + T_1^2}{2} - T_1 T \right)
\]
\[
+ \frac{PI}{T} \left[ \frac{D(p) \left[ e^{\theta T} - \theta T_1 \frac{T}{2} - 1 \right]}{\theta} \right]
\]
\[
+ \frac{D(p)(M - T_1)}{\theta^2} \left[ e^{\theta T} - \theta T_1 - 1 \right]
\]
\[
-\frac{\alpha \beta p^{\beta-1} T}{T} \left[ \frac{1}{\theta^2} \left( e^{\alpha \beta - \theta T_1 + \frac{\theta T^2}{2}} - 1 \right) \right] + \\
\frac{\alpha \beta p^{\beta-1} T}{T} \left[ \frac{1}{\theta^2} \left( e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right) \right]
\]

\[
t = \frac{\partial^2 Z_1(p, T)}{\partial p^2} = \frac{p(\theta T_1 - 1)}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

\[
t = \frac{p(\theta T_2 - 1)}{\theta T} \left[ e^{\alpha \beta - \theta T_1 + \frac{\theta T^2}{2}} - 1 \right]
\]

And:

\[
s = \frac{\partial^2 Z_1(p, T)}{\partial p^2} = \frac{\alpha \beta p^{\beta-1} T}{T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

Case 2: \( M < T < N \).

The interest earned, \( IE_2 \) during \([0, M]\) is Eq. 17:

\[
IE_2 = P \int_0^M D(p) \cdot t \, dt = P \int_0^M \alpha p^\beta \cdot t \, dt
\]

\[
= P \alpha p^\beta \frac{M^2}{2} = \frac{1}{2} \alpha p^\beta M^2
\]

The retailer pays for \( Q \) units purchased at time \( t = 0 \) at the rate of \( C \) \$/unit to the supplier during \([0, M]\). The retailer sells \( D(p) \) \( M \) units at selling price \( P \) \$/unit. So, he has generated revenue of \( PD(p) M + IE_2 \).

Then two sub cases may arise:

Sub case: 2.1: Let \( p D(p) M + IE_2 \geq CQ \), i.e., retailer has enough money to pay for all \( Q \) units procured. Then interest charge will be Eq. 18:

\[
t_{2.1} = \frac{\partial^2 Z_{2.1}(p, T)}{\partial T^2} = \frac{-h(\theta T + 1)}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

And:

\[
s_{2.1} = \frac{\partial^2 Z_{2.1}(p, T)}{\partial T^2} = \frac{-h(\theta T + 1)}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

For maximizing the total net profit, provided Eq. 23-26:

\[
r_2, t_{2.1} - s_{2.1} < 0
\]

Where:

\[
r_{2.1} = \frac{\partial^2 Z_{2.1}(p, T)}{\partial p^2} = -\frac{h(\theta T + 1)}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

The optimal values of \( p = p_{2.1} \) and \( T_1 = T_{2.1} \) are solutions of Eq. 21 and 22:

\[
\frac{\partial}{\partial p} Z_{2.1}(p, T) = \alpha p^\beta + \alpha \beta p^{\beta-1} - \alpha p^\beta + \frac{\alpha \beta p^{\beta-1} T}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

And:

\[
\frac{\partial}{\partial T} Z_{2.1}(p, T) = -\frac{h}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

The net profit Eq. 20:

\[
Z_{2.1}(p, T) = GR - OC - HC - DC - SC - IC_{2.1} + IE_{2.1}
\]

\[
Z_{2.1}(p, T) = (p - c) \alpha p^\beta - A - \frac{h \alpha p^\beta}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right]
\]

\[
- \frac{c \alpha p^\beta}{\theta T} \left[ e^{\alpha \beta - \theta T_2 + \frac{\theta T^2}{2}} - 1 \right] - \frac{S \alpha p^\beta}{\theta T}
\]

\[
\left( T^2 + T_1^2 - 2T \right) + \frac{\alpha \beta p^{\beta-1} T}{\theta T} \left( T^2 + T_1^2 - 2T \right)
\]

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Sub Case: 2.2: Let \( p \cdot D(p) > M + IE \). Here retailer will have to pay interest on unpaid balance.

\[ U_1 = c \cdot D(p) - [p \cdot D(p) - M + IE] < 0 \]

At time \( M \) to the supplier. Then interest paid, \( I_c \), per unit time is given by Eq. 27:

\[
I_c = \frac{e^{\theta (M - T_1)} - e^{\theta (M - T_2)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right]
\]

And Interest earned Eq. 28:

\[
Z_{2.2}(p, T_1) = \frac{e^{\theta (T_1 - M)} - e^{\theta (T_2 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_1 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_2 - M)}}{\theta T_1}
\]

The optimal values of \( p \) and \( T_1 \) are solutions of Eq. 30 and 31:

\[
\frac{\partial}{\partial T_1} Z_{2.2}(p, T_1) = \frac{e^{\theta (T_1 - M)} - e^{\theta (T_2 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_1 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_2 - M)}}{\theta T_1} = 0
\]

And:

\[
\frac{\partial}{\partial p} Z_{2.2}(p, T_1) = \frac{e^{\theta (T_1 - M)} - e^{\theta (T_2 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_1 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_2 - M)}}{\theta T_1}
\]

Case 3: \( T_1 \geq N \): Based on the total purchased cost, \( CQ \), total money \( p \cdot D(p) > M + IE \) in account at \( M \) and total money \( p \cdot D(p) \geq N + IE \) at \( N \), there are three sub cases may arise:

Sub Case 3.1: Let \( p \cdot D(p) > M + IE \) and

\[
\frac{\partial}{\partial T_1} Z_{2.2}(p, T_1) = \frac{e^{\theta (T_1 - M)} - e^{\theta (T_2 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_1 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_2 - M)}}{\theta T_1}
\]

Sub Case 3.2: Let \( p \cdot D(p) \geq N + IE \) and

\[
\frac{\partial}{\partial p} Z_{2.2}(p, T_1) = \frac{e^{\theta (T_1 - M)} - e^{\theta (T_2 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_1 - M)}}{\theta T_1} - \left[ \frac{T_1 + T_2}{2} - T_1 \right] \frac{e^{\theta (T_2 - M)}}{\theta T_1}
\]

Sub Case 3.3: Let \( p \cdot D(p) \geq N + \frac{p \cdot D(p) \cdot I_c}{2} < CQ \).
And:

\[
pD(p) \cdot (N - M) + \frac{plD(p) \cdot (N - M)^2}{2} < CQ - \left[ pD(p) \cdot M + IE_2 \right]
\]

Here, retailer does not have enough money to pay off total purchase cost at \( N \). He will do payment of \( pD(p) + IE \) at \( M \) and \( pD(p) \cdot (N - M) + \frac{plD(p) \cdot (N - M)^2}{2} \) at \( N \). So, he has to pay interest on unpaid balance \( \left[ pD(p) \cdot M + IE \right] \) with \( Ic_i \) interest rate during \( (M, N) \) and

\[
U_2 = U_1 \left[ pD(p) \cdot (N - M) + \frac{plD(p) \cdot (N - M)^2}{2} \right]
\]

with interest rate \( Ic_i \) during \( (N, T_1) \).

Therefore, total interest charged on retailer; \( IC_{3,3} \) per unit time is Eq. 36:

\[
IC_{3,3} = K_i + \sum_{j=1}^{3} \left[ Ic_j \cdot \left( e^{\alpha (T_j - N)} - \theta (T_j - N) - 1 \right) \right]
\]

Interest earned per unit time is:

\[
IE_{3,3} = \frac{IE_2}{T} - \frac{pM^2 \alpha p^\beta}{2T}
\]

The net profit is:

\[
Z_{3,3}(p, T_j) = GR - OC - HC - DC - SC - IC_{3,3} + IE_{3,3}
\]

\[
= (p - c) \alpha p^\beta - \frac{A}{T} - \frac{bD(p)}{T} \left\{ e^{\alpha T_j - \theta T_j} - \frac{eD(p)}{T} \right\}
\]

\[
\left\{ e^{\alpha T_j - \theta T_j} - \frac{SoD(p)}{T} \left( T_j^2 + T_j^2 - TT_j \right) \right\}
\]

\[
- \sum_{j=1}^{3} \left[ Ic_j \cdot \left( e^{\alpha (T_j - N)} - \theta (T_j - N) - 1 \right) \right] - \frac{\alpha p^\beta \lambda eM^2}{2T}
\]

The optimum values of \( p = p_{3,3} \) and \( T_1 = T_{3,3} \) are solutions of Eq. 37:

\[
\frac{\partial}{\partial p} Z_{3,3}(p, T_j) = \partial D(p) \left\{ e^{\alpha T_j - \theta T_j} - \frac{eD(p)}{T} \right\}
\]

\[
- \frac{\alpha D(p)}{T} \left( T_j - T \right) + \frac{U_1 Ic_2}{pT} \left( e^{\alpha (T_j - N)} - 1 \right) = 0
\]

And:

\[
\frac{\partial}{\partial T_j} Z_{3,3}(p, T_j) = \frac{bD(p)}{T} \left\{ e^{\alpha T_j - \theta T_j} - \frac{eD(p)}{T} \right\}
\]

\[
+ \frac{\alpha D(p)}{T} \left( T_j - T \right) \left( \frac{U_1 Ic_2}{pT} \left( e^{\alpha (T_j - N)} - 1 \right) \right) = 0
\]

To maximize the net profit, provided:

\[
t_3 < s_3 < 0 \quad (39)
\]

\[
t_3 = \frac{\partial^2}{\partial T_j^2} Z_{3,3}(p, T_j) = -\frac{bD(p)}{T} \left\{ e^{\alpha T_j - \theta T_j} - \frac{eD(p)}{T} \right\}
\]

\[
- \frac{\alpha D(p)}{T} \left( T_j - T \right) \left( \frac{U_1 Ic_2}{pT} \left( e^{\alpha (T_j - N)} - 1 \right) \right) = 0
\]

Algorithm for optimal solution: Step 1: Compute \( T_1 = T_{1,1} \) and \( p = p_{1,1} \) from case-1:

Step 2: If \( T_1 < M \).

Then calculate:

\[
Z(p, T_j) = \max \{ Z(p, T_j) \}
\]

Where \( I = 1, 2.1, 2.2, 3.1, 3.2, 3.3 \).

Step 3: If \( M < T_1 < N \).
If $pD(p) > N$ is true but $p$ is not increased, then compute $T_2 < T_3$, from subcase 3.2.

Step 4: $M < T_3$ is not true then computes $T_1 = T_{3.3}$ and $p = p_{3.3}$ from sub case 3.3, repeat step 2 and stop.

**Numerical examples**: The preceding theory can be illustrated by the following numerical example where the parameters are given as follows:

- Demand parameter, $\alpha = 10,000$
- Selling price, $p = 13$
- Deterioration rate, $\beta = 0.03$
- Deterioration cost $C = 0.05$
- Shortage cost $S = 3$
- Holding cost $h = 2.5$
- First delay period, $M = 0.08$
- Sec delay period, $N = 0.1$
- The interest earned, $I_1 = 0.05$
- The interest charged, $I_{c1} = 0.12$
- The interest charged, $I_{c2} = 0.20$
- $T = 10$

<table>
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<tr>
<th>$n$</th>
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<th>$P$</th>
<th>$\text{Profit}_1(p, T_1)$</th>
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<tbody>
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<td>1</td>
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Using the above algorithm, we obtain the computational results as shown in Table 1-3.

**Results**: The data obtained clearly shows that individual optimal solutions are very different from each other. However, there exists a solution which ultimately provides the Maximize the total profit operating of inventory system. In the above tables, it is observed that as the value of $T_1$ and $p$ are increased and then the total cost is increased. Thus, the optimal solution of the problem is $Z(p, T_1) = 76.8586$ at $(p, T_1) = (0.952656, 0.128844)$.

**CONCLUSION**

In this study, we introduced a new idea of trade credits, namely, the supplier charges the retailer progressive interest rates if the retailer prolongs its unpaid balance. By offering progressive interest rates to the retailers, a supplier, can secure competitive market advantage over the competitors and possibly improve market share profit.

Shortages are allowed and completely backlogged in the present model. In many practical situations, stock out is unavoidable due to various uncertainties. There are many situations in which the profit of the stored item is higher than its back order cost. Consideration of shortages is economically desirable in these cases. The traditional parameters of holding cost is assumed here to be time varying. As the changes in the time value of money and in the price, index, holding cost cannot remain constant over time. It is assumed that the holding cost is linearly increasing function of time.

We developed theoretical results to obtain the optimal replenishment interval by examine the explicit condition. We proposed an algorithm to find the optimal ordering policy. A numerical study has been performed to observe the sensitivity of the effect of demand parameter changes. Further, the model can be enriched by incorporating other realistic parameters such as Weibull distribution deterioration rate, inflation rate, partial backlogging and in progressive interest charges.

**REFERENCES**


