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Original Article

EOQ Inventory Model for Non-Instantaneous Deteriorating Items with Imperfect Quality under Advance-Cash-Credit Payment Policy

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Abstract - *In classical supplier-retailer-customer supply chain inventory models, the supplier offers the retailer full trade credit and the retailer in turn provides the partial trade credit to its customer to stimulate sales, revenue, and reduce inventory. However, in today's business transactions, a supplier usually asks retailer to pay via the advance-cash-credit (ACC) payment scheme that includes three payment methods: advance payment, cash payment, and credit payment. So, advance payment is amounts paid for the business in advance before the goods and services are received; cash payment is amounts paid for the business at the time of receiving an order and credit payment is amounts paid for the business at a later date without any additional charges. In this article, we develop an Economic Order Quantity (EOQ) model for non-instantaneous deteriorating items with imperfect quality in which a screening process is applied to identify imperfect items under the ACC payment scheme. In addition, if the customer makes a partial payment of the total purchasing cost in cash at the time of the delivery of the the goods, then the retailer gives the customer the opportunity to pay the remaining purchasing cost at a later date without any additional charges. The major objectives of this model are to determine the retailer's optimal selling price and cycle time such that the retailer's profit per unit time is maximized. Finally, numerical examples are provided to illustrate the model and concavities of the profit function are shown graphically.*

Keywords **-** *Inventory model, Non-instantaneous deteriorating items, and advance-cash-credit (ACC) payment scheme.*

1. Introduction and Literature Review

Many researchers assume that the deterioration of the items in a supply chain begins from the instant of their arrival in the stock. But, most of the items such as first-hand vegetables, fruits, foodgrains, pulses and dals, and medicines maintain their freshness or quality or originality over a time period; that is, during this time period, deterioration of the items does not occur. After that time period, these items begin to deteriorate. This phenomenon is defined as the non-instantaneous deterioration of the items. Wu et al. (2006) first studied an optimal replenishment policy for non-instantaneous deteriorating items with stock-dependent demand and partial backlogging where the demand is assumed to be stock-dependent. Subsequently, many researchers such as Ouyang et al. (2006), Geetha and Uthayakumar (2010), Chang et al. (2010, 2015), Maihami and Kamalabadi (2012), Soni (2013), Wu et al. (2014), Wang et al. (2015), Tsao (2016, 2017), Mashud et al. (2018), Mahato and Mahata (2021) have developed the inventory models for non-instantaneous deteriorating items under various conditions.

The traditional inventory models do not investigate advance-cash-credit (ACC) payment methods and assume that the payment is made immediately upon receiving the goods or a interest-free credit period is provided for the full payment to the customers. However, in modern business transactions, advance-cash-credit (ACC) payment scheme is commonly used by manufacturers, suppliers, or retailers to improve their own benefits. The retailer is required to prepay a fraction of the procurement cost as an advance to buy items, then pay another fraction of the procurement cost in cash upon receiving the ordered goods and receive a short interest-free credit term to pay the remainder of the procurement cost. This payment method is known as an advance-cash-credit (ACC) payment scheme.
Li et al. (2017) developed a supplier-retailer-customer chain in which the retailer receives an upstream advance-cash-credit (ACC) payment from the supplier while in return offers a downstream cash-credit payment to customers. Wu et al. (2018) studied the inventory policies for perishable products with expiration dates under advance-cash-credit payment schemes. Li et al. (2019) developed an inventory model interfaced with marketing, operations, and finance in a supplier-retailer chain under

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ACC payment policy. They demonstrated that an increase in the fraction of advance payment raises selling price, while an increase in the fraction of credit payment reduces selling price. Other studies related to inventory model with ACC payment methods include Chang et al. (2019), Tsao et al. (2019), Liao et al. (2021), Yang et al. (2021), and so on.

Pricing of the product is always an important strategic tool used to adjust consumer demand. We consider a selling price-dependent demand in this model. In this paper, we develop an EOQ inventory model for non-instantaneous deteriorating items with imperfect quality in which a screening process is applied to identify imperfect items under the ACC payment scheme. Mathematical modelling and computational analyses are used to determine the retailer's optimal selling price and cycle time to maximize the retailer's profit per unit time. Numerical examples are used to demonstrate the proposed inventory model.

2. Assumptions and Notations

Assumptions: The proposed EOQ inventory model is developed under the following assumptions.

1. Only one type of item is considered.
2. The items are deteriorating in nature and the rate of deterioration is time dependent. For simplicity, the deterioration rate $\theta(\mathrm{t})$ is taken as $\theta(\mathrm{t})=\theta t$, where $0 \le \theta << 1$.
3. There is no replacement or repairment of deteriorated items during the replenishment cycle time.
4. The demand of the items are assumed to be a linear function of selling price and is taken as $D(p)=a-bp$, where $a,b \ge 0$.
5. Replenishment is instantaneous and shortages are not allowed.
6. The time horizon is infinite and lead time is negligible.
7. The retailer makes the payment according to advance-cash-credit (ACC) payment policy. In ACC payment policy, the payment is made in the following manner.
   a) The retailer pays α fraction of procurement cost as advance payment at the time when the contract of items is given to the supplier.
   b) The retailer pays another β fraction of procurement cost as cash payment at the time when the supplier delivers the ordered items to the retailer.
   c) The retailer receives a credit period of M years to pay the remaining τ fraction of procurement cost as credit payment.
8. The retailer also offers a partial trade credit period to its customers. If customers make a partial payment $(1-\rho)$ of the purchase amount in cash at the time of purchasing, then they receive a credit period of N years to pay the remaining ρ fraction of the purchase amount.
9. The retailer's credit period offered by the supplier M must be greater and equal than the customer's credit period offered by the retailer N i.e. $\mathrm{M} \ge \mathrm{N}$.
10. To manage the quality of the items, there exists an inspection process that is 100% effective. The screening rate is faster than the demand rate.

Notations: The proposed EOQ inventory model is developed under the following notations.

Notations	Description
$\mathrm{a,b}$	: Demand parameters
Q	: Order quantity in units per replenishment cycle
r	: Rate of the screening of the items
v	: Percentage of defective items in Q
θ	: Deterioration parameter with $0 \le \theta << 1$
α	: Fraction of procurement cost to be paid as advance payments by the retailer before the time of delivery of items, $0 \le \alpha \le 1$;

β	: Fraction of procurement cost to be paid as cash payments by the retailer at the time of delivery of the items, $0 \le \beta \le 1$;
τ	: Fraction of procurement cost to be granted a credit period $[0, M]$ from the supplier to the retailer, $0 \le \tau \le 1$ and $\alpha + \beta + \tau = 1$.
ρ	: Fraction of the purchase amount that is granted the trade credit period by the retailer to its customers with $0 \le \rho \le 1$.
M	: Length of retailer's credit period offered by the supplier.
N	: Length of customer's credit period offered by the retailer with $M \ge N$.
t_l	: Length of time during which the prepayments are paid as advance payment.
t_s	: Length of screening time per replenishment cycle with $t_s \le t_d \le T$.
t_d	: Length of time in which the product has no deterioration i.e. fresh product time.
T	: Length of the inventory replenishment cycle time.
O	: The ordering cost per order;
h	: The holding cost per unit per unit time;
c	: The procurement cost per unit;
p	: The selling price of the item per unit;
d	: The deterioration cost per unit per unit time;
s	: The screening cost per unit;
I_e	: Rate of interest earned by the retailer.
I_c	: Rate of interest charged by the supplier to the retailer with $I_c \ge I_e$.
$I_1(t)$	: Inventory level during the time interval $[0, t_s]$
$I_2(t)$	: Inventory level during the time interval $[t_s, t_d]$
$I_3(t)$	: Inventory level during the time interval $[t_d, T]$

3. Mathematical Formulation of the Proposed EOQ Inventory Model

In this section, a mathematical model is formulated to describe the EOQ inventory model under advance-cash-credit payment policy. Initially, the retailer gives an order of size Q units for an item at time $t = -t_l$ and receives it from the supplier at time $t = 0$. The inventory level are continuously decreasing due to the cumulative effects of customer's demand and defectiveness of the items during the screening period $[0, t_s]$, $t_s = \frac{Q}{r}$. The screening process is completed at time $t = t_s$. The inventory level are continuously decreasing due to customer's demand only during the time interval $[t_s, t_d]$. Then, the inventory level are continuously decreasing due to the cumulative effects of customer's demand and deterioration of the items during the time period $[t_d, T]$ and becomes zero at time $t = T$. The behavior of the inventory level over time is shown in figure1.

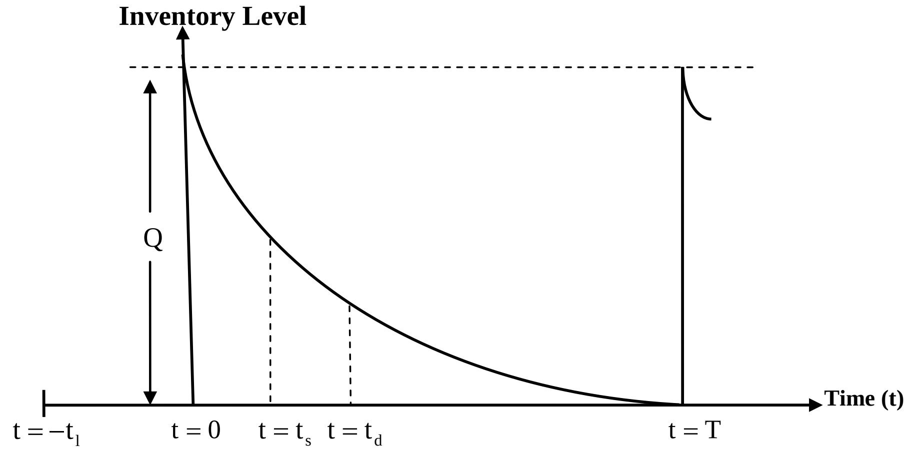


Fig.1: The graphical representation of behavior of the inventory level over time

The inventory level at any instant of time is represented by the following differential equations:

$$I_1'(t) = -D(p), \qquad 0 \le t \le t_s \tag{1}$$

$$I_2'(t) = -D(p), \qquad t_s \le t \le t_d \tag{2}$$

$$I_3'(t) = -\theta(t)\, I_3(t) - D(p), \qquad t_d \le t \le T \tag{3}$$

with the boundary conditions:

$$I_1(0) = Q, \;\; I_2(t_s) = (1-v)Q - \int_0^{t_s} D(p)dt = (1-v)Q - D(p)\, t_s, \; I_3(T) = 0 \tag{4}$$

By using the above conditions (4), the differential equations (1), (2) and (3) are solved and their solutions are given by the following equations:

$$I_1(t) = Q - D(p)\, t = Q - (a-bp)\, t, \qquad 0 \le t \le t_s \tag{5}$$

$$I_2(t) = (1-v)Q - D(p)\, t = (1-v)Q - (a-bp)\, t, \qquad t_s \le t \le t_d \tag{6}$$

$$I_3(t) = (a-bp)\left\{(T-t) + \frac{\theta}{6}\left(T^3 - 3Tt^2 + 2t^3\right)\right\}, \qquad t_d \le t \le T \tag{7}$$

Using continuity of condition $I_2(t_d) = I_3(t_d)$, we obtain the retailer's order quantity per replenishment cycle

$$Q = \frac{(a-bp)}{1-v}\left\{T + \frac{\theta}{6}\left(T^3 - 3Tt_d^2 + 2t_d^3\right)\right\} \tag{8}$$

Retailer's profit per replenishment cycle consists of the following components:

1. The ordering cost per order is given by

$$\text{OC} = O \tag{9}$$

2. The sales revenue per replenishment cycle is calculated as

$$\text{SR} = p\int_0^T D(p)\, dt = p\;(a-bp)\; T \tag{10}$$

3. The procurement cost per replenishment cycle is calculated as

$$\text{PC} = cQ = \frac{c(a-bp)}{1-v}\left\{T + \frac{\theta}{6}\left(T^3 - 3Tt_d^2 + 2t_d^3\right)\right\} \tag{11}$$

4. The screening cost per replenishment cycle is given by

$$\text{SC} = sQ = \frac{s(a-bp)}{1-v}\left\{T + \frac{\theta}{6}\left(T^3 - 3Tt_d^2 + 2t_d^3\right)\right\} \tag{12}$$

5. The deterioration cost per replenishment cycle is calculated as

$$DC = d\left\{ I_2(t_d) - \int_{t_d}^{T} D(p)\, dt \right\} = d\{(1-v)Q - (a-bp)T\} = \frac{d(a-bp)\theta}{6}\left(T^3 - 3Tt_d^2 + 2t_d^3\right) \qquad (13)$$

6. The holding cost per replenishment cycle is calculated as

$$\mathrm{HC} = h\left\{ \int_0^{t_s} I_1(t)\, dt + \int_{t_s}^{t_d} I_2(t)dt + \int_{t_d}^{T} I_3(t)dt \right\}$$

$$\mathrm{HC} = h(a-bp)\left[\frac{1}{2}T^2 + \frac{\theta}{12}\left(T^4 - 4Tt_d^3 + 3t_d^4\right) + \frac{v(a-bp)}{r(1-v)^2}\left\{ T^2 + \frac{\theta}{3}\left(T^4 - 3T^2t_d^2 + 2Tt_d^3\right)\right\}\right] \qquad (14)$$

7. The interest charged for advance payment per replenishment cycle is computed as

$$\mathrm{IC}_{\alpha} = c\alpha I_c D(p)\left\{ \int_{-t_l}^{N} T dt + \int_{N}^{T+N} (T+N-t)dt \right\} = \frac{c\alpha I_c(a-bp)}{2}\left\{2T(N+t_l) + T^2\right\} \qquad (15)$$

8. The interest charged for cash payment per replenishment cycle is computed as

$$\mathrm{IC}_{\beta} = c\beta I_c D(p)\left\{ \int_{0}^{N} T dt + \int_{N}^{T+N} (T+N-t)dt \right\} = \frac{c\beta I_c(a-bp)}{2}\left\{2TN + T^2\right\} \qquad (16)$$

Now, we computed the interest charged and earned for credit payment per replenishment cycle. Since the retailer's credit period offered by the supplier (M) must be greater and equal than the customer's credit period offered by the retailer (N) i.e. $\mathrm{M} \geq \mathrm{N}$, then there are two possible cases that might arise:

Case1: $\mathrm{M} \geq \mathrm{T} + \mathrm{N}$ i.e. the retailer's credit period (M) is longer than the time $(\mathrm{T}+\mathrm{N})$ at which the retailer receives the last payment from its customers.

The retailer receives sales revenue from its customers and deposits it into an interest bearing account in order to earn interest. In this situation, the retailer receives all revenue from its customers at time $(\mathrm{T}+\mathrm{N})$ and is able to pay off the entire credit payment at the end of the credit period M. Therefore, the interest charged for credit payment per replenishment cycle is zero.

$$\mathrm{IC}_{1\tau} = 0 \qquad (17)$$

The interest earned for credit payment per replenishment cycle is computed as

$$\mathrm{IE}_{1\tau} = p\tau I_e D(p)\left[\rho\left\{ \int_{N}^{T+N} (t-N)dt + \int_{T+N}^{M} T dt \right\} + (1-\rho)\left\{ \int_0^T t dt + \int_T^M T dt \right\}\right]$$

$$\mathrm{IE}_{1\tau} = \frac{pI_e\tau(a-bp)}{2}\left\{2T(M-\rho N) - T^2\right\} \qquad (18)$$

In this case, the retailer's profit per unit time is given by

$$\mathrm{Z}_1 = \frac{1}{\mathrm{T}}\left\{ \mathrm{SR} - \mathrm{OC} - \mathrm{PC} - \mathrm{SC} - \mathrm{DC} - \mathrm{HC} - \mathrm{IC}_{\alpha} - \mathrm{IC}_{\beta} - \mathrm{IC}_{1\tau} + \mathrm{IE}_{1\tau} \right\} \qquad (19)$$

Case2: $\mathrm{M} \leq \mathrm{T} + \mathrm{N}$ i.e. the retailer's credit period (M) is shorter than the time $(\mathrm{T}+\mathrm{N})$ at which the retailer receives the last payment from its customers. To calculate the interest charged by the supplier and earned by the retailer, this case can be divided into two different subcases, $\mathrm{M} \leq \mathrm{T} \leq \mathrm{T} + \mathrm{N}$ and $\mathrm{T} \leq \mathrm{M} \leq \mathrm{T} + \mathrm{N}$.

Subcase2.1: $\mathrm{M} \leq \mathrm{T} \leq \mathrm{T} + \mathrm{N}$. In this situation, the interest charged for credit payment per replenishment is computed as

$$\mathrm{IC}_{2.1\tau} = c\tau I_c D(p)\left\{ \rho \int_{M}^{T+N} (T+N-t)dt + (1-\rho)\int_M^T (T-t)dt \right\}$$

$$\mathrm{IC}_{2.1\tau}=\frac{c\tau I_c(a-bp)}{2}\left\{\rho\left(N^2-2MN\right)+(T-M)^2\right\} \tag{20}$$

And the interest earned for credit payment per replenishment is also computed as

$$\mathrm{IE}_{2.1\tau}=p\tau I_e D(p)\left\{\rho\int_N^M(t-N)dt+(1-\rho)\int_0^M t\,dt\right\}=\frac{p\tau I_e(a-bp)}{2}\left\{\rho\left(N^2-2MN\right)+M^2\right\} \tag{21}$$

In this subcase, the retailer's profit per unit time is given by

$$\mathrm{Z}_{2.1}=\frac{1}{\mathrm{T}}\left\{\mathrm{SR}-\mathrm{OC}-\mathrm{PC}-\mathrm{SC}-\mathrm{DC}-\mathrm{HC}-\mathrm{IC}_\alpha-\mathrm{IC}_\beta-\mathrm{IC}_{2.1\tau}+\mathrm{IE}_{2.1\tau}\right\} \tag{22}$$

Subcase2.2: $\mathrm{T}\le\mathrm{M}\le\mathrm{T}+\mathrm{N}$. In this situation, the interest charged for credit payment per replenishment is computed as

$$\mathrm{IC}_{2.2\tau}=c\tau I_c D(p)\left\{\rho\int_M^{T+N}(T+N-t)dt\right\}=\frac{1}{2}c\tau I_c(a-bp)\rho(T+N-M)^2 \tag{23}$$

And the interest earned for credit payment per replenishment is also computed as

$$\mathrm{IE}_{2.2\tau}=p\tau I_e D(p)\left\{\rho\int_N^M(t-N)dt+(1-\rho)\left\{\int_0^T t\,dt+\int_T^M T\,dt\right\}\right\}$$

$$\mathrm{IE}_{2.2\tau}=\frac{p\tau I_e(a-bp)}{2}\left\{\rho(M-N)^2+(1-\rho)\left(2MT-T^2\right)\right\} \tag{24}$$

In this subcase, the retailer's profit per unit time is given by

$$\mathrm{Z}_{2.2}=\frac{1}{\mathrm{T}}\left\{\mathrm{SR}-\mathrm{OC}-\mathrm{PC}-\mathrm{SC}-\mathrm{DC}-\mathrm{HC}-\mathrm{IC}_\alpha-\mathrm{IC}_\beta-\mathrm{IC}_{2.2\tau}+\mathrm{IE}_{2.2\tau}\right\} \tag{25}$$

Hence, the retailer's profit per unit time for the inventory system is given by

$$\mathrm{Z}=\begin{cases}\mathrm{Z}_1 & \text{if}\quad M\ge T+N\\ \mathrm{Z}_{2.1} & \text{if}\quad M\le T\le T+N\\ \mathrm{Z}_{2.2} & \text{if}\quad T\le M\le T+N\end{cases} \tag{26}$$

4. Computational Analysis

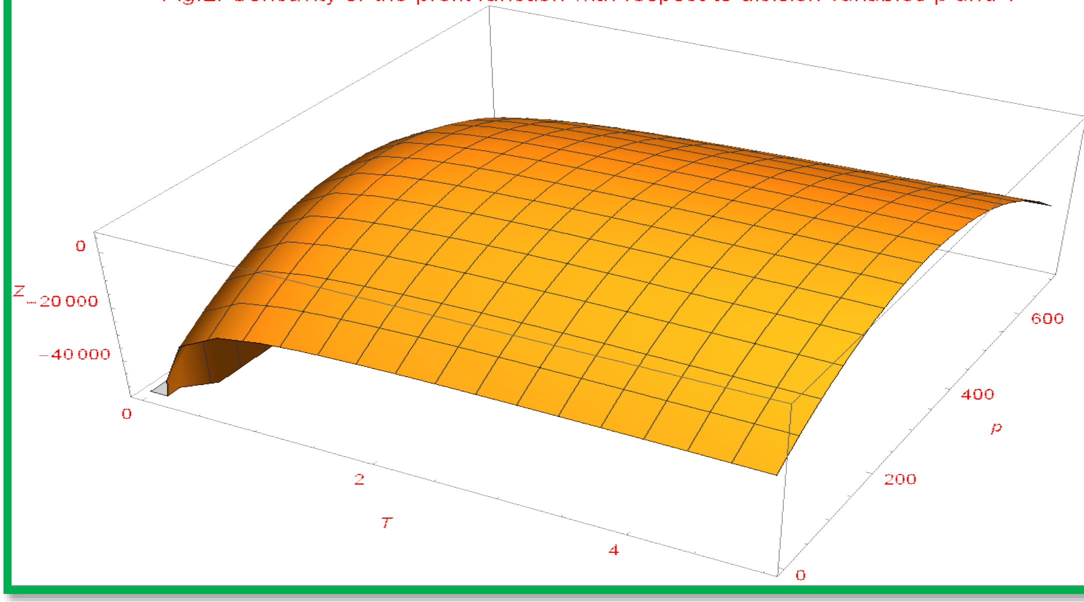
The purposes of computational analysis are to find the optimal selling price (p) and replenishment cycle time (T) and to show the concavity of the profit function with respect to the decision variables selling price (p) and replenishment cycle time (T) for each cases.

Example1 : Let $a=100$, $b=0.2$, $O=$ Rs 5000 per order, $c=$ Rs 100 per unit, $s=$ Rs 4 per unit, $h=$ Rs 3 per unit per year, $d=$ Rs 2 per unit per year, $I_e=12\,\%$ per rupee per year, $I_c=15\,\%$ per rupee per year, $v=25\%$, $\alpha=30\%$, $\beta=30\%$, $\tau=40\%$, $\rho=45\%$, $\theta=0.01$, $r=500$ units per unit time, $t_d=2$ years, $t_l=2$ years, $M=7$ years and $N=2$ years.

Applying the Mathematica 11.2 software, we obtain the following optimum results:

$T^*=3.09162$ year, $p^*=$ Rs 326.09 per unit, $Q^*=144.03$ units, and $Z^*=$ Rs 5763.27

Fig.2: Concavity of the profit function with respect to dicision variables p and T

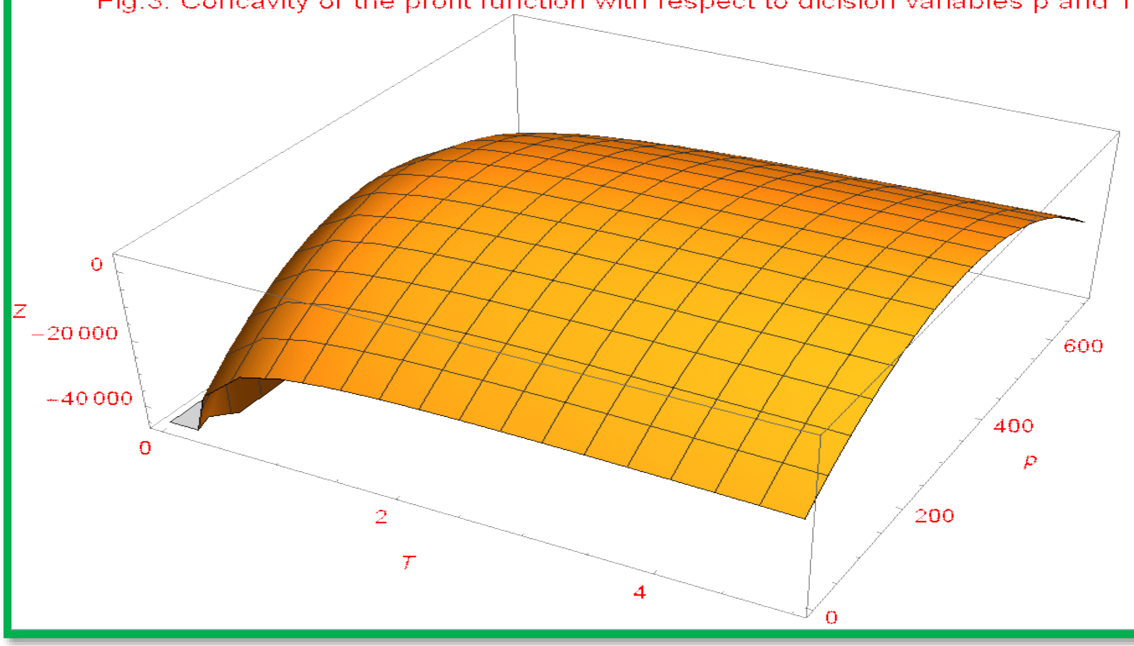


Example2 : Let $a = 100$, $b = 0.2$, $O = \text{Rs } 5000$ per order, $c = \text{Rs } 100$ per unit, $s = \text{Rs } 4$ per unit, $h = \text{Rs } 3$ per unit per year, $d = \text{Rs } 2$ per unit per year, $I_e = 12\,\%$ per rupee per year, $I_c = 15\,\%$ per rupee per year, $v = 25\%$, $\alpha = 30\%$, $\beta = 30\%$, $\tau = 40\%$, $\rho = 45\%$, $\theta = 0.01$, $r = 500$ units per unit time, $t_d = 2$ years, $t_1 = 2$ years, $M = 3$ years and $N = 2$ years.

Applying the Mathematica 11.2 software, we obtain the following optimum results:

$$T^* = 3.48978 \text{ year}, \ p^* = \text{Rs } 339.43 \text{ per unit}, \ Q^* = 150.614 \text{ units, and } Z^* = \text{Rs } 3925.07$$

Fig.3: Concavity of the profit function with respect to dicision variables p and T



Example3 : Let $a = 100$, $b = 0.2$, $O = \text{Rs } 5000$ per order, $c = \text{Rs } 100$ per unit, $s = \text{Rs } 4$ per unit, $h = \text{Rs } 3$ per unit per year, $d = \text{Rs } 2$ per unit per year, $I_e = 12\,\%$ per rupee per year, $I_c = 15\,\%$ per rupee per year, $v = 25\%$, $\alpha = 30\%$, $\beta = 30\%$, $\tau = 40\%$, $\rho = 45\%$, $\theta = 0.01$, $r = 500$ units per unit time, $t_d = 2$ years, $t_l = 2$ years, $M = 5$ years and $N = 2$ years.

Applying the Mathematica 11.2 software, we obtain the following optimum results:

$$T^* = 3.15468 \text{ year}, \; p^* = \text{Rs } 333.91 \text{ per unit}, \; Q^* = 141.27 \text{ units, and } Z^* = \text{Rs } 4684.74$$

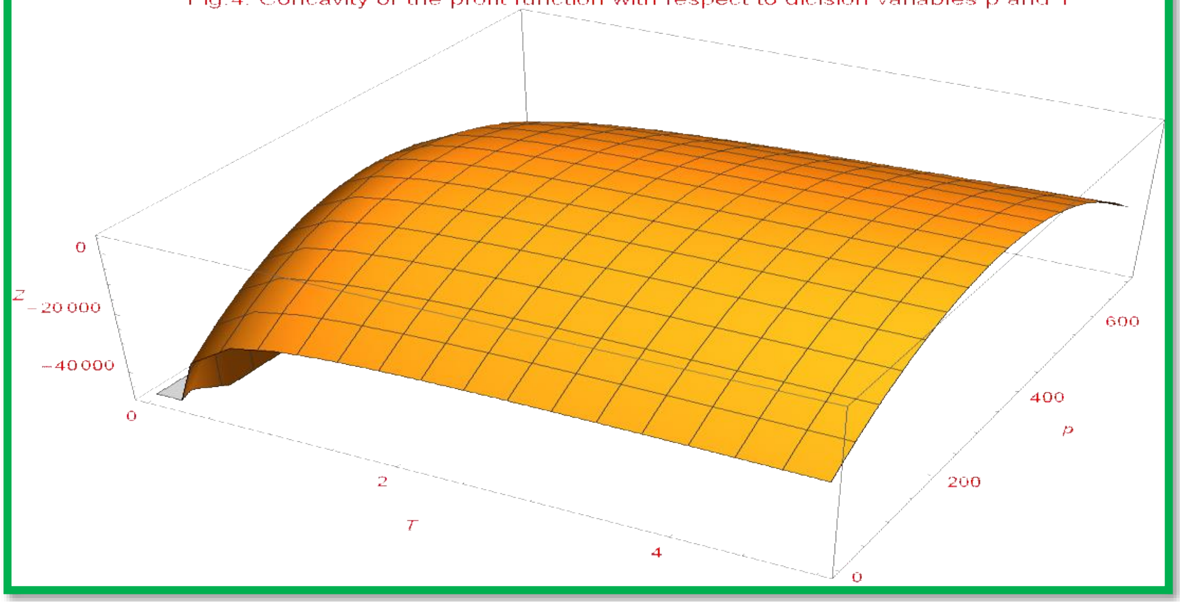


Fig.4: Concavity of the profit function with respect to dicision variables p and T

5. Conclusion

Most of the existing inventory models under advance-cash-credit (ACC) payment scheme are assumed that the demand rate remains constant. However, in practice the market demand is always changing rapidly and is affected by several factors such as price of the items, time, stock level, and trade credit period. In this article, we have developed an EOQ model for non-instantaneous deteriorating items under the ACC payment scheme by considering demand to a linear non-increasing function of selling price. It was assumed that the rate of deterioration of the items gradually increases with time. we have also applied a screening process to identify imperfect items in the received goods from supplier. In addition, retailer have offered a partial trade credit to its customer to boost the sales. We have obtained the retailer's optimal selling price and cycle time by maximizing the profit function. Finally, numerical examples have been provided to illustrate the model and concavities of the profit function have been shown graphically.

This model can be extended in several ways, for example, we may consider a time-varying demand rate. Also, we can extend this model to allow for shortages and partially backlogging. Finally, the effect of inflation rates can also be considered.

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