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Deterministic Inventory Model with Price-Dependent Demand and Allowable Delays in Payments in the Context of Learning Effects for Object Degradation

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Abstract - This study develops a comprehensive inventory model addressing the joint effects of price-dependent demand, product degradation, allowable payment delays, and learning curve impacts. Utilizing differential equations and boundary conditions, the methodology derives optimal replenishment policies and cycle times to minimize total costs, including holding, deterioration, shortage, and interest-related expenses. Numerical examples demonstrate that incorporating degradation and credit policies significantly reduces inventory costs and enhances supply chain efficiency. Sensitivity analyses reveal that parameters such as delay period, deterioration rate, and shipment frequency critically influence optimal strategies. The findings provide valuable insights for retailers and suppliers to optimize inventory management under realistic conditions involving product perishability, demand fluctuations, and credit terms. Overall, the model offers a practical framework for improving decision-making in inventory control, contributing to more resilient and cost-effective supply chain operations.

Key Word : ***Inventory management; Stock-dependent demand; Price-sensitive demand; Trade credit; Deteriorating items; Imperfect production; Weibull distribution; Integrated inventory model; Supply chain optimization***

1.INTRODUCTION

Efficient and effective inventory management is of paramount importance to all organizations to ensure maximum profits. This focuses on optimal research into inventory management. In particular, Inventory research has increased significantly over the past 20 years. Several researchers have sought to develop supply chain management with a realistic approach and industrial applications, taking into account various Parameter and assumptions. Recently, commercial balances have proven to be an effective tool to increase organizational sales and profits. Therefore, providers are directly motivated to allow customers to pay their customers at certain times without penalties for improving the product. Even if an acceptable delay in payment reduces the cost of holding inventory. It actually eases short-term funds. Especially for small, capital-only companies. Additionally, retailers may collect additional revenue during the allowable delay period, as they invested in either a bank or a market investment. Thus, acceptable delays provide a delicious alternative for small finances to stimulate new demand for the product, additional customer issues. Retailers may result in additional charges for unpaid fees if the customer does not pay at a certain time. Recently, degradation effects actual importance affect practical inventory opportunities. Deterioration is related to the collapse of the durability of the product, disappointing the original quality of the product before final consumption. Researchers address different types of degradation and demand patterns to find the best solution. Here, the proposed model considers certain degradation effects via inventory. A combination of stimulates retailers' additional revenues by this hinders the concept of acceptable late payments.

Demand rate is a function that allows you to always differentiate time. If the customer is satisfied with the price and quality of the perishable object, the requirement remains constant in the second phase, known as the "Ramp" request, as the request reacts as a function of time incrementally. This demand is easily observed during festive seasons like Christmas, Dussehra, Diwali etc. This demand rose in early October and sales will rise linearly as they constantly reach December.

The more realistic situations exist in the market, lamp demand deserves comprehensive research. Observe that corrosive objects are wasted during storage due to physical deposition. This waste attracts customer inflation and retailer losses. This can be avoided if you have determined the optimal drawing cycle time for your inventory. Therefore, the proposed study can observe degradation effects through inventory. As a result, retailers can minimize the associated costs per hour. At the same time, supplier's retailers can absorb order behavior through proposed research. We create Mathematical Models the optimal inventory strategy through and use two advantages: allowable delays in payments and junctions of ideas compared to inventory. The basic mathematical models are introduced at the start and then presented in numerical examples. Therefore, the proposed research through effective inventory management has benefited greatly from retailers.

2.LITERATURE REVIEW

In today's competitive business transactions, it is common for suppliers to offer specific fixed loans to retailers to stimulate demand. During this loan, retailers can collect income and earn interest on this sale. However, the supplier calculates interest in outstanding balances beyond this period. Therefore, acceptable delays reduce the cost of holding shares indirectly. Meanwhile, retail credits offered by suppliers encourage retailers to purchase more. Therefore, it is also a powerful advertising tool to attract new customers who view it as an alternative incentive guideline for quantitative discounts. Therefore, commercial credit can play an important role in inventory management for both suppliers and retailers (see Jaggi, Goyal & Goel, 2008) [1].

Hill (1995)[2] proposed an inventory model in which variable branches are in all performance functions. Research in this field continues in Mandal and Pal (1998), Wu and Ouyang (2000), and Wu (2001). In the above task, the optimal replenishment guidelines require a decision time to reach zero inventories. Deng, Lin and Chu (2007) [7] first covered the stock model proposed by Mandal and Pal (1998) [3] and Wu and Ouyang (2000)[4], both of which occurred.

Panda, Saha and Basu (2007)[5] constructed an inventory model for degradation of objects (with three parameters and registered degradation rates) with generalized exponential ramp question quotas and full feedback. Skouri, Constantaras, Papachristos and Ganas (2009)[6] and Deng et al. (2007)[7] By introducing general Ramp surveys and Weibull degradation. According to Harris, inventory is basically broken down due to a constant demand.

Tripathy and Mishra [8] presented the model assuming allowable delays in payments based on cash flow. Karmakar and Choudhary [9] examined inventory models where demand for common ramp types represents demand quotas, partial deficits, and holding costs over time. They get two different guidelines taking into account stock filling into consideration. Using bottlenecks, there's no shortage. The inventory model of degradation was developed by Amutha and Chandraskaran[10]. This also takes into account the time and partial deficit.

Singh and Pattnayak [11] looked at models that exacerbate the product. In that deterministic model, the demand rate decreases exponentially and payments are also permitted. A deterministic model of product deterioration was developed by Roy. There, deterioration is currently proportional and demand is accepted as a selling price function. The proposed model allows for late payments and assumes inflation.

Anchal et al.[12] presented a non-inhaled waste model with learning effects. In their models, bottlenecks arise and partially advance. Degradation rates are assumed as a two-parameter female distribution in the proposed model. Maragatham and Palani [13] presented a deterministic inventory model of demand rates as a function of sales price. In their models, bottlenecks occur at lead time. Duari and Chakraborti [14] have formulated an order of the amounts in which a single warehouse is considered to be a deterioration of products with bottlenecks and demand rates.

The EOQ model for product deterioration was by Khanra et al.[15]. They accepted demand as square time dependent and also gave acceptable payment delays. Min et al. handed over a production model that is considering product deterioration and demand quotas. They also take a delay in paying. Ouyang et al.[16] presented the model taking into account incomplete production processes and allowable delays in payments.

The current work has attempted to develop a mathematical model for a worsening inventory system. Demand rates depend on price and also take into account the delays allowed at the time of payment. Bottlenecks are also allowed. The cost of the learning curve and the resulting cost of ordering. Validate the model using numerical examples. Another sensitivity analysis was performed to determine the effect of the parameters involved in the final solution.

For this reason, many articles dealing with various existing models under different trade loans have appeared in the literature in recent years. Table-1 summarizes the most important assumptions of the models presented in the relative literature. However, it has been observed that the demand rate for new brands begins at the beginning of the season up to a certain moment and that the remaining time is constant. For example, demand rates rise during the growth phase and the market grows to a stable level, so demand remains constant by the end of the inventory cycle. The term "Ramp type" is used to present such a demand pattern.

Therefore, the ramp function rate function has two different time segments. In his first segment, demand is a function of time increase. However, demand remains constant for the second time. All ramp request functions between two time segments have at least one fragment point L, in which they are not distinguished. This non-differential fracture makes the analysis of the problem more complicated. This asked researchers to investigate inventory models for Ramp type demand samples.

Table1: Key assumptions of inventory models with permissible delay in payments.

Name of Authors	Demand rate	Allowing for deterioration	Allowing for shortages	Trade credit period
Goyal (1985)	Constant	No	No	Fixed
Dave(1985)	Constant	No	No	Fixed
Aggarwal and Jaggi (1995)	Constant	Constant rate	No	Fixed
Jamal et al.(1997)	Constant	Constant rate	Complete backlogging	Fixed
Chang and Dye (2001)	Constant	Constant rate	Time dependent	Fixed
Teng (2002)	Constant	No	No	Fixed
Chang et al. (2003)	Time dependent	Time dependent rate	No	Depending on the ordering quantity
Shah (2006)	Constant	Constant rate	Complete backlogging	Fixed
Huang (2007)	Constant	No	No	Fixed, but partially delay in payments
Jaber and Osman (2006)	Constant	No	Yes	Decision variable
Jaber (2007)	Increasing	No	No	Fixed
Jaggi et al.(2008)	**Function of the credit-period**	No	No	Fixed
Ouyang et al .(2009)	Constant	Constant	No	Partially permissible delay in payments linked to order quantity
Teng and Chang (2009)	Constant	No	No	Two levels of trade credit policy
Kreng and Tan (2010)	Constant	No	No	Two levels of trade credit policy

3.ASSUMPTIONS AND NOTATIONS:-

The model works upon the given notations and assumptions:

3.1. Assumptions

1. Only one item is involved in the inventory system.
2. Lead time is considered as zero.
3. The planning horizon is considered of infinite length.
4. Shortages are allowed to occur.
5. Demand rate is price dependent and $R(t) = \frac{K}{pe}$, $0 \leq t < T$
6. A credit period which is fixed is provided by the supplier for settling the retailer's accounts.
7. Holding cost and ordering cost follows the learning curve.
8. Deterioration rate is assumed as constant.

3.2. Notations

- q(t) : Inventory level at time t.

- K= K(n): $\left(k_0 + \frac{k_1}{n^{\gamma}}\right): learning\ coefficient\ ordering\ cost$
- n: number of shipments.
- γ : learning factor
- A: the purchasing cost.
- S : the shortage cost
- d : deterioration cost.
- θ : constant deterioration rate
- p : price per unit
- h(n): $\left(h_0 + \frac{h_1}{n^{\gamma}}\right)$: the holding cost per unit excluding charges of interest.
- I_e : interest earn
- I_p: interest charged.
- M : permissible delay in settling accounts
- Q : maximum inventory level.
- T : length of order cycle.
- T_1 : time in which inventory level becomes zero, $0 \leq T_1 \leq T$.
- TC (T_1,T) : the total of inventory cost per unit time.

4. MATHEMATICAL FORMULATION AND SOLUTION

A mathematical model is formulated for perishable products where demand rate depends upon the price. As per the assumption, the planning period is considered of infinite length. The inventory level becomes zero, at time T_1 ,and then occurrence of shortages starts during the time period T_1 to T.

Let q(t) represents the inventory level at any time t ≥ 0. The following differential equation describes the state of q(t) at any time t is

$$\frac{dq(t)}{dt} + \theta(t)q(t) = -\frac{k}{p^e} \ , \ 0 \leq t \leq T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

The boundary conditions for the equation (1) is $q(T_1)= 0$ at $t= T_1$.

Under these boundary conditions, the solution of the equation (1) is

$$q(t) = \frac{-kp^{-e}}{\theta} + \frac{kp^{-e}}{\theta}\left[e^{\theta T_1}.e^{\theta t}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Inventory achieves its maximum level by putting q(0) =Q in equation (2).

$$\text{Therefore,} q_{max} = Q = q(0) = \frac{-kp^{-e}}{\theta} + \frac{kp^{-e}}{\theta}\left[e^{\theta T_1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

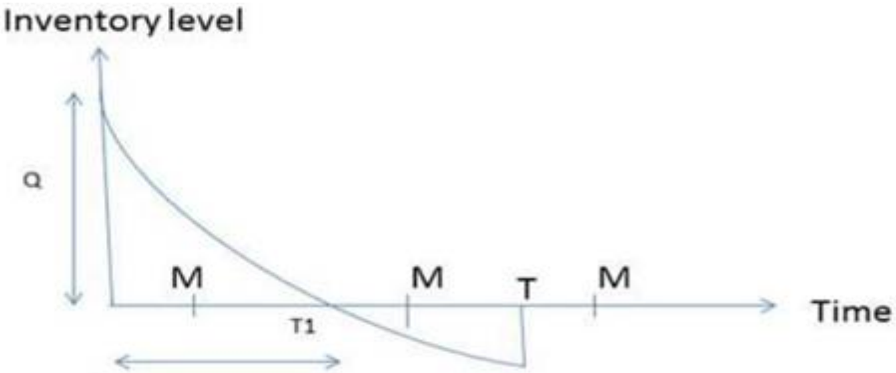

Fig.-i: Graphical representation of inventory system

During time interval [0, T1], inventory is available in the system. Therefore holding cost during this time period is:

Holding Cost$(HC) = \left(h_0 + \frac{h_1}{n^\gamma}\right)\int_0^{T_1} q(t)dt$

Therefore, $HC = \left(h_0 + \frac{h_1}{n^\gamma}\right)\left[\frac{-kp^{-e}\theta T_1 - kp^{-e} + kp^{-e}e^{\theta T_1}}{\theta^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$

Shortages start in system due to stock outs during time interval$[T_1,]$. Therefore, the shortage cost (SC) is:

$$SC = -S\int_{T_1}^{T} q(t)dt$$

$$SC = -S\left[\frac{-kp^{-e}}{\theta}(T - T_1) - \frac{kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} + \frac{kp^{-e}}{\theta^2}\right] \ldots\ldots\ldots\ldots.(5)$$

Deterioration cost (DC)is computed during period[0,1]is

Deterioration cost $DC = q(t) - \int_{T_1}^{T} R(t)dt$

$$DC = d\left[\frac{-kp^{-e}}{\theta} - \frac{-kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} - kp^{-e}T_1\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The Total cost can be calculated as follows

$$TC(T_1, T) = \frac{1}{T}[OC + HC + SC + DC] \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots.(7)$$

If the interest charged and interest earned based upon cycle time T, then there can be three following conditions:

I) $M \le T_1 \le T$

II) $T_1 < M \le T$

III) $M \ge T$

Case I: $M \le T_1 \le T$

The interest earned by the buyer's during the period 0 to M on the average sales earning rate $I_e$is$\frac{AI_e}{2}kp^{-e}M^2$.Further, the buyer has to settle the account at credit period M and must

arrange for the funds to pay the seller for the fixed inventory store at the pre-determined rate of interest, I_p . Therefore, the buyer's paid interest for the unsold items after M is given by:

$$IP = AI_p\left[\frac{-kp^{-e}}{\theta}(T_1 - M) + \frac{-kp^{-e}}{\theta^2}e^{\theta(T_1 - M)} - \frac{-kp^{-e}}{\theta^2}\right]$$

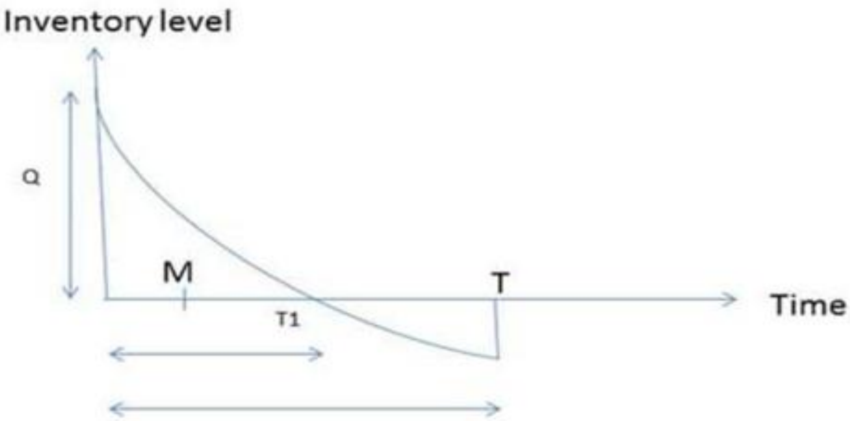

Fig.-ii : inventory structure for case I

In the following equation$TC_1(T_1,T)$is the total cost for the case I is given as.

$$TC_1(T_1,T) = \frac{1}{T}[OC + HC + DC + SC + IP - IE_1] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots.(8)$$

$$= \frac{1}{T}\Bigg[K + \left(h_0 + \frac{h_1}{n^\gamma}\right)\left[\frac{-kp^{-e}\theta T_1 - kp^{-e} + kp^{-e}e^{\theta T_1}}{\theta^2}\right] + d\left[\frac{-kp^{-e}}{\theta} + \frac{kp^{-e}}{\theta^2}e^{\theta(T_1-T)} - kp^{-e}T_1\right]$$
$$- S\left[\frac{-kp^{-e}}{\theta}(T-T_1) - \frac{kp^{-e}}{\theta^2}e^{\theta(T_1-T)} + \frac{kp^{-e}}{\theta^2}\right] + AI_p\left[\frac{-kp^{-e}}{\theta}(T_1 - M) + \frac{kp^{-e}}{\theta^2}e^{\theta(T_1-M)} - \frac{kp^{-e}}{\theta^2}\right]$$
$$- \frac{Al_e}{2}kp^{-e}M^2\Bigg] \ldots(9)$$

Case II :$T_1 < M \leq T$

In this case, no interest is paid by buyer during $T_1 < M \leq T$, but earns interest at an annual rate I_e during the period (0, M). Therefore, the buyer's earn interest is $Pl_e\left[\frac{kp^{-e}T_1^2}{2} + kp^{-e}T_1(M - T_1)\right]$ and the paid interest is zero.

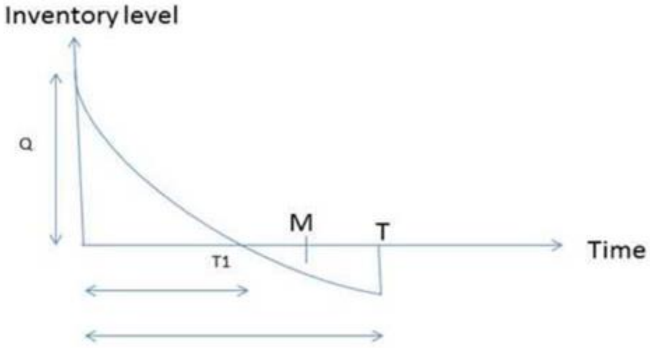

Fig.-iii : inventory structure for case II

In the following equation $TC_2(T_1,T)$is the total cost for the case II is given as.

$$TC_2(T_1,T) = \frac{1}{T}[OC + HC + DC + SC + IP - IE_2] \ldots\ldots\ldots\ldots.(10)$$

$$= \frac{1}{T}\left[K + \left(h_0 + \frac{h_1}{n^{\gamma}}\right)\left[\frac{-kp^{-e}\theta T_1 - kp^{-e} + kp^{-e}e^{\theta T_1}}{\theta^2}\right] + d\left[\frac{-kp^{-e}}{\theta} + \frac{kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} - kp^{-e}T_1\right] - S\left[\frac{-kp^{-e}}{\theta}(T - T_1) - \frac{kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} + \frac{kp^{-e}}{\theta^2}\right] - AI_e\left[\frac{-kp^{-e}T_1^2}{2} + kp^{-e}T_1(M - T_1)\right]\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Case III :$M \geq T$

In this case, also no interest is paid by buyer as $M \geq T$, but interest earned IE_3 is $l_e[kp^{-e}T_1(M - T_1)]$.

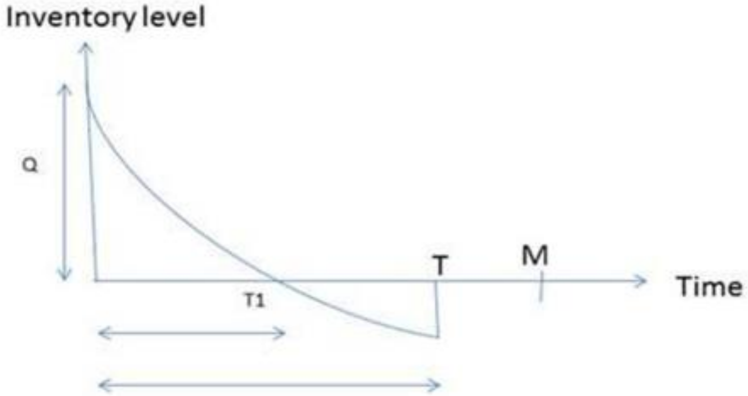

Fig.-iv: inventory structure for case III

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$$TC_3(T_1, T) = \frac{1}{T}[OC + HC + DC + SC + IP - IE_3] \ldots\ldots\ldots\ldots (12)$$

$$= \frac{1}{T}\left[\begin{array}{c} K + \left(h_0 + \frac{h_1}{n^{\gamma}}\right)\left[\frac{-kp^{-e}\theta T_1 - kp^{-e} + kp^{-e}e^{\theta T_1}}{\theta^2}\right] + d\left[\frac{-kp^{-e}}{\theta} + \frac{kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} - kp^{-e}T_1\right] \\ -S\left[\frac{-kp^{-e}}{\theta}(T - T_1) - \frac{kp^{-e}}{\theta^2}e^{\theta(T_1 - T)} + \frac{kp^{-e}}{\theta^2}\right] - Al_e[kp^{-e}T_1(M - T_1)] \end{array}\right] \ldots (13)$$

5.SOLUTION PROCEDURE

Our purpose is to obtain the minimal cost of the system. The necessary condition for minimizing the cost is:

$$\frac{\partial TC(T_1, T)}{\partial T_1} = 0\,, \qquad \frac{\partial TC(T_1, T)}{\partial T} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Provided that this equation satisfies the following conditions

$$\frac{\partial^2 TC(T_1, T)}{\partial T_1^2} > 0\,, \qquad \frac{\partial^2 TC(T_1, T)}{\partial T^2} > 0 \; and$$

$$\left(\frac{\partial^2 TC(T_1, T)}{\partial T \partial T_1}\right)^2 - \left(\frac{\partial^2 TC(T_1, T)}{\partial T_1^2}\right)\left(\frac{\partial^2 TC(T_1, T)}{\partial T^2}\right) < 0 \ldots\ldots (15)$$

By solving (14), the values of $T_1$and T can be calculated and by using this optimal value, the minimal total cost of inventory system can be calculated.

6.Numerical Example

For Case I :

Let us take T= 5.70914, h_0= 4, h_1= 3, n= 1, γ= .02, k= 50000, p= 10, e= 2.67, θ= 0.18, T_1= 0.913449, d= 0.4, S=1.4, A= 20, I_p = 0.15/year, M=.013year, I_e= 2, Then TC=362.7381961487

For Case II :

Let us take T= 5.70914, h_0= 4, h_1= 3, n= 1, γ= .02, k= 50000, p= 10, e= 2.67, θ= 0.18,
T_1= 0.913449, d= 0.4, S= 1.4, A= 20, I_p = 0.15/year, M= 5, I_e= 2. Then TC= 152.0891853310

For Case III:

Let us take T= 5.70949, h_0= 4, h_1= 3, n= 1, γ= .02, k= 50000, p= 10, e= 2.67, θ= 0.18,
T_1= 0.913449, d= 0.4, S= 1.4, A= 20, I_p = 0.15/year, M= 10, I_e= 2, Then TC= 27.886078

7.Sensitivity Analysis:

This section presents the sensitivity analysis in order to illustrate the proposed model. To show the variation of values of different parameters on optimal solution, sensitivity analysis has been done and tables are given below to show the effect of different parameters on the cycle length and the total cost.

Table 2: Effect the value of M on cycle length and total cost

M	Cycle length	Total cost
5	5.70914	75.6798
10	5.70949	75.6284
15	5.70983	75.5770
20	5.71017	75.5256

Table 3: Effect of deterioration rate on cost and cycle length.

No. of Shipments	T_1	Cycle length	Total cost
1	0.913449	5.70914	75.6798
2	0.915031	5.70947	75.6676
3	0.915949	5.70966	75.6606
4	0.916597	5.70980	75.6556
5	0.917097	5.70991	75.6518

Table4: Effect of number of shipments (n) on optimal solution.

θ	T_1	Cycle length	Total cost
0.7	0.4615	2.9475	596.6431
0.8	0.4452	2.9430	599.4622
0.9	0.4308	2.9393	602.0433
1.0	0.4178	2.9362	604.4248

Graphical representation of the Model

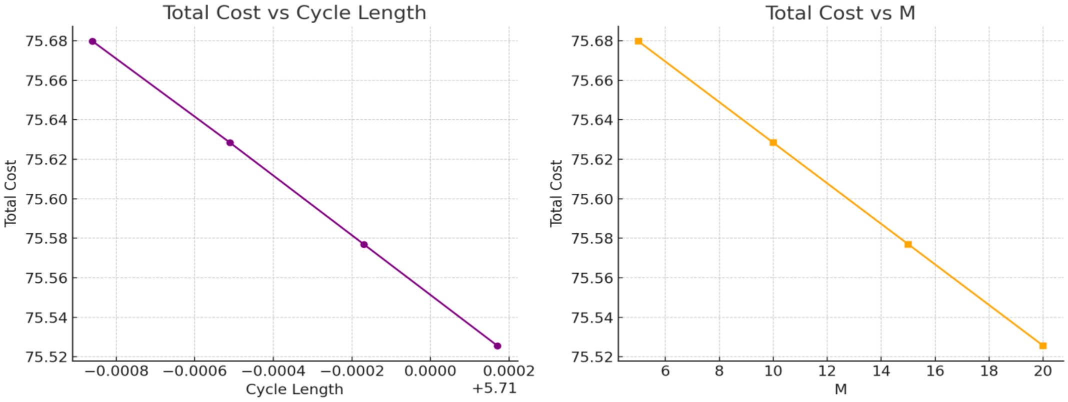

Fig. -v: Total Cost vs Cycle Length and Total Cost vs M

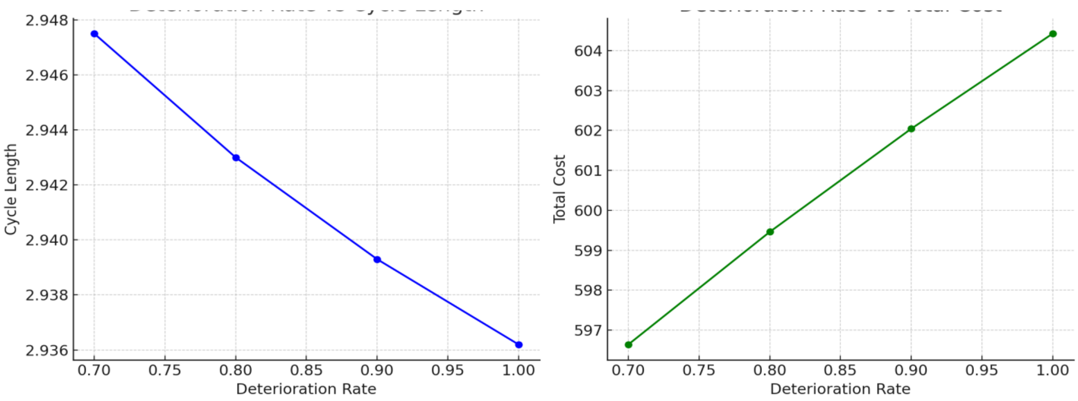

Fig.-vi: Deterioration Rate vs Cycle Length and Deterioration Rate vs Total Cost

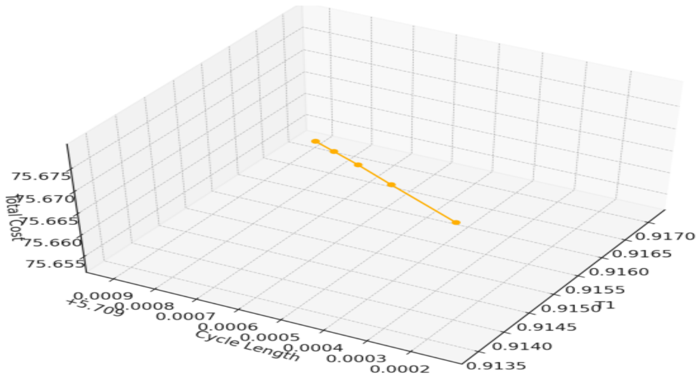

Fig –vii: 3D graph of T_1 vs. Cycle Length vs. Total Cost

All observations from Table (2–4) and Figure (5–7) are based on the results of calculations. Table 2 shows that as the value of M increases, the cycle length increases but the total cost value decreases. Table 3 observes it as the degradation rate, cycle length and total cost increase. Table 4 can be easily observed that values of T1 & T increase and total cost values decrease with increasing number of shipments. Similarly, diagram (5–7) shows the effects of degradation rate on the number of programs, learning factors, and cycle length or total cost. This model reflects the amount that should be given to the buyer an order quantity. Buyers want to accept the learning phenomenon that learns new tasks after repeated frequently, minimizing the total cost for more profits. In this article, after all values are obtained from three or more cases, we conclude that Case-I is suitable for the best solution. This case shows approximate values for all parameters.

8. CONCLUSIONS

In this article, a mathematical model was developed under the assumption
(i) the demand quota is price dependent
(ii) the degradation rate is constant
(iii) late payments are permitted
(iv) bottle necks are permitted
(v) including learning effects.

To minimize the total cost, OOQ (optimal ordinal quantity) and optimal cycle time are calculated. The diagrams of the above model provide the appropriate algorithms. Validate the results by taking into account examples of numerical values. Another sensitivity analysis is performed to determine the effect of the parameters involved in the final solution.

This model can be further expanded by taking more realistic assumptions such as inflation rates, partial deficits, and more. You can generalize the model to a stochastic demand pattern. We also were able to consider the effects of various degradation, such as weibull parameters and gamma distribution.

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