International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

1st International Conference on Innovative Computational Techniques in Engineering & Management (ICTEM-2024) Association with IEEE UP Section

Two Level Trade Credit Criteria and Discount Policy for Deteriorating Items with Linearly Increasing Demand

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DOI: https://doi.org/10.55248/gengpi.6.sp525.1931

ABSTRACT

In order to increase retailer profits, this study presents an inventory system designed for trended demand and assuming linear temporal dependence. It takes into account predetermined credit durations from suppliers and credit periods for customers to represent the actual market dynamics. Sensitivity analysis helps determine which inventory parameters are most important to optimise. The usefulness of the model is validated with a numerical example. The work advances inventory management by addressing the intricacies of credit-based and time-dependent demand transactions. Performance and profitability are maximised by the model through a methodical evaluation of parameter modifications. Findings show how accurately the model represents credit transactions and demand patterns, facilitating well-informed decision-making. In summary, this study provides retailers with a strategic framework to effectively handle inventory, satisfy consumer expectations, and optimise profits in ever-changing market conditions.

KEYWORDS: Inventory Model; Linearly Dependent Demand; Two-Level Trade Credit

1. INTRODUCTION

In the current dynamic and competitive business environment, a company's ability to effectively manage its inventory is critical to its success. In the face of shifting consumer expectations and market conditions, businesses are always looking for new and creative ways to improve inventory strategy and boost profitability. Because perishable goods are prone to spoiling or obsolescence and can result in considerable financial losses if not managed skillfully, managing them in an environment of in-creasing demand presents special challenges. In addition, the complexity is in-creased by linearly expanding demand patterns, necessitating customised inventory models for the best possible management. Businesses have resorted to complex inventory management techniques, like the integration of discount policies and two-level trade credit criteria, to handle these difficulties. By offering alternative credit terms to suppliers and customers, these tactics enable firms to postpone paying sup-pliers while giving credit to customers, enhancing cash flow and reducing debt. At the same time, discount policies encourage customers to make larger purchases and lower the expenses associated with businesses keeping inventory. This dual strategy, when properly tailored to handle perishable items with linearly increasing demand, provides significant advantages, guaranteeing profitability and cost-effectiveness throughout the supply chain. This study aims to explore the effectiveness of Two-Level Trade Credit Criteria and Discount Policy in reducing the difficulties of handling perishable items with linear demand growth. The goal of the research is to clarify the best credit terms and discount rates that lead to increased profitability and decreased inventory costs using real-world data and advanced mathematical models.

This research is motivated by the imperative requirement for companies in sec-tors like electronics, pharmaceuticals, and some food to have strong inventory management plans in place when dealing with perishable or quickly deteriorating commodities. Mismanagement of such commodities can have significant financial re-percussions, thus creative ways to reduce risks and take advantage of opportunities are required. This study's main research question is: Can the integration of discount policy and two-level trade credit criteria effectively address the issues related to managing perishable goods with linear demand growth, improving profitability and lowering inventory costs? The use of Two-Level Trade Credit Criteria and Discount Policy, which are especially designed for the management of perishable goods with linear demand growth, is empirically explored in this research, adding to the body of information already in existence. The study intends to provide practical recommendations for companies looking to optimise their inventory management procedures in dynamic market set-tings by utilising real-world data and sophisticated mathematical modelling approaches.

2. LITERATURE REVIEW

[1] introduced the first inventory model in 1913. This inventory model is most commonly referred to as the EOQ inventory model. It was predicated on a very small number of core and restrictive presumptions. After that, a substantial quantity of research work was needed. The inventory model by [1] has been investigated in a number of real-world situations. In the EOQ inventory model, demand is considered to be constant, and shortages are not allowed. However, in practice, demand varies and is dependent on a number of variables, such as time, price, stock, expiration date, and attractive discount rate, among others. Integrated inventory models with permitted payment delays were developed by [2]. In these models, client demand is responsive to the buyer's pricing. In supply chain management, the models assess the two-level trade credit policy in vendor-buyer and buyer-customer relationships. [3] created an inventory model with conditionally acceptable payment delays and two-level trade credit financing. Steady demand is assumed by the model. After that, [4] developed an inventory model that considered a partial trade credit policy instead of creating a full trade credit policy. A linear non-decreasing function of time was assumed for demand in an inventory model developed by [5], which also incorporated an acceptable payment delay under two tiers of trade credit. [6] developed a lot size inventory model for degrading items with acceptable payment delays and stock reliance. [7] developed a two-level trade credit finance inventory model for non-instantaneously decaying products. The demand is seen as being downstream credit related in this paradigm. EOQ models with partial trade financing upstream and full trade financing downstream. [8] created an inventory model for an integrated three-layer supply chain system with non-instantaneous receipt, exponentially decaying products under two tiers of trade credit, and constant demand. [9] developed a manufacturer-retailer inventory model for degrading items with price-sensitive credit-linked demand using a two-tier trade credit financing and revenue sharing contract. [10] created an inventory model for degrading items with a two-level partially trade credit that permits shortages and price-dependent demand. An integrated inventory model of a manufacturer and a supplier operating under a two-level trade credit contract was created by [11]. The manufacturer's inventory model is based on the EPQ model. For manufactured commodities, there is price-dependent demand and an exponential rate of deterioration. Shortages are acceptable to the manufacturer, and they have a full backlog for the upcoming term. An exponentially oriented inventory model (EOQ) was developed by [12] for a decaying item with exponentially distributed deterioration and continuous demand. You cannot make it too brief. In 2021, [13] created an inventory model for demand that is based on stock and expiration rates in a two-level trade credit system where shortages are permitted and partially backlogged.

3. NOTATIONS AND ASSUMPTIONS

Notations: A few presumptions are made in order to create the A few presumptions are made in order to create the mathematical model:

A = Ordering cost in dollar per Order

c = Purchasing cost in dollar per item

p = Unit selling price in dollar per item p>c

h = Holding cost in dollar per unit per time excluding interest charges

r = Continuous discount rate

I(t)= Inventory level at time t

T = Cycle length

Q = Retailer's order quantity per cycle

V= length of permissible delay offered by the supplier to retailer in years.

U= length of permissible delay offered by the retailer to customer in years.

Assumptions: There are some assumptions that we use throughout the study-

- Lead time is zero and time horizon is assumed as infinite.
- Instantaneous replenishments and shortages are allowed.
- There is no repair and replenishment of the deteriorated inventory.
- A constant $\theta(0 < \theta < 1)$ fraction of the on-hand inventory deteriorates per unit per time.
- Demand rate is assumed as linearly increasing with time. Which is given by $D(t) = a + bt$, where a and b are positive constant.
- When $U \leq T$, the account is settled at $U = T$and the retailer would pay for the interest charges on things in stock at the rate I_p across the interval $[U, T]$; the account is also settled at $T = U$, and the retailer does not have to pay any interest charges on items in stock throughout the cycle.

- The retailer can generate revenue and earn interest if the consumer pays the whole purchase price to them until the end of the credit period that the supplier has provided. In other words, the store can generate income and earn interest at the rate I_e (per $ annually) from U to V as long as trade credit is maintained.
- The fixed credit duration supplied by the supplier to the retailer to his/her customer is no less than $0 < U \leq V$.

4. MATHEMATICAL FORMULATION OF INVENTORY MODEL

According to the aforementioned assumptions, degradation and demand-related depletion will happen at the same time. The systems inventory level will be described by the following differential equations:

$$I'(t) + \theta I(t) = -(a + bt) \qquad 0 < t \leq T \tag{1}$$

The solution of above equation is:

$$\mathrm{I(t)} = \frac{1}{\theta}[(a - b + bt)e^{\theta(T-t)} - (a - b + bt)] \tag{2}$$

So, the retailer's order size per cycle is:

$$Q = I(0) = \frac{1}{\theta}[(a - b)(e^{\theta T} - 1)] \tag{3}$$

1. Order cost: $S_o = \frac{A}{1-e^{-rT}}$

2. Holding cost: $S_H = \frac{h}{(1-e^{-rT})}\int_0^T I(t)e^{-rt}\,dt$

$$= \frac{h}{\theta}\left[\frac{(a-b+bT)(e^{\theta T}-e^{-rT})}{(\theta+r)(1-e^{-rT})} - \frac{(a-b)}{r} + \frac{b}{r} + \frac{bTe^{-rT}}{r(1-e^{-rT})}\right]$$

3. Purchasing cost: $S_P = \frac{cQe^{-rv}}{1-e^{-rT}}$

$$= \frac{c}{\theta(1-e^{-rT})}\left[(a - b + bT)e^{\theta T} - (a - b)\right]$$

Case 1: $0 < T \leq U$

In this case, due to the account is settle before the given time period of permissible delay in payments, the interest charged will be zero i.e.

$S_{C1} = 0$

The interest earned in this case

$$S_{E1} = \frac{pI_e}{1 - e^{-rT}}\int_U^V e^{-rt}\int_0^T D(\mu)d\mu dt$$
$$= \frac{pI_e}{1-e^{-rT}}\left[\frac{(e^{-rU}-e^{-rV})}{r}\left(aT + \frac{bT^2}{2}\right)\right]$$

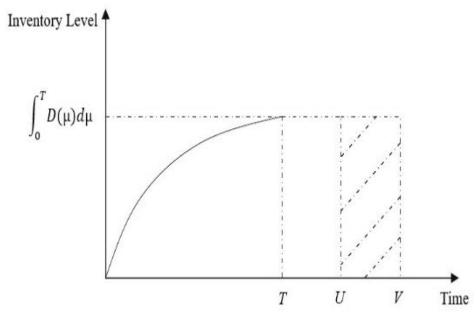


Figure 1. The total accumulation of interest earned when $0 < T \leq U$

Case 2: $U < T \leq V$

The interest charged will zero in this case this case also because the account will be settled within the given time period of permissible delay in payments i.e.

$$S_{C2} = 0$$

The interest earned in this case

$$S_{E2} = \frac{pI_e}{1 - e^{-rT}}\left[\int_U^T e^{-rt}\int_0^t D(\mu)d\mu dt + \int_T^V e^{-rt}\int_0^T D(\mu)d\mu dt\right]$$
$$= \frac{pI_e}{(1 - e^{-rT})r}\left[(a + bT)e^{-rT} + a(u - 1)e^{-ru} + \frac{b(U^2 - U)e^{-rU}}{2} - e^{-rV}\left(aT + \frac{bT^2}{2}\right)\right]$$

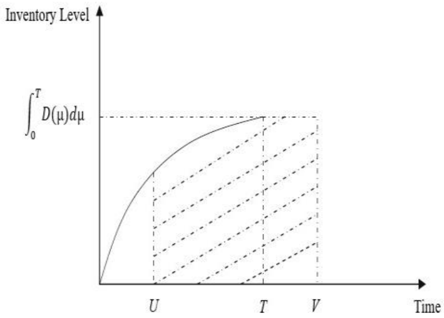


Figure 2. The total accumulation of interest earned when $U < T \leq V$

Case 3: $V < T$

In this case the interest charged will be

$$S_{C3} = \frac{cI_p}{1 - e^{-rT}} \int_V^T I\,(t) e^{-rt} dt$$

$$= \frac{cI_p}{1-e^{-rT}} \left[\frac{(a-b+bT)}{(\theta+r)} \left\{ \frac{\theta e^{-rT}}{r} + e^{\theta T} - \theta U - rV \right\} - \frac{(a-b+bV)e^{-rV}}{r} + \frac{b(e^{-rV} - e^{-rT})}{r} \right]$$

The interest earned in this case

$$S_{E3} = \frac{pI_e}{1 - e^{-rT}} \int_U^V e^{-rt} \int_0^t D(\mu) d\mu dt$$

$$= \frac{pI_e}{r(1-e^{-rT})} \left[\left\{ a(1 - V) + \frac{b(2V - V^2)}{2} \right\} e^{-rV} \right]$$

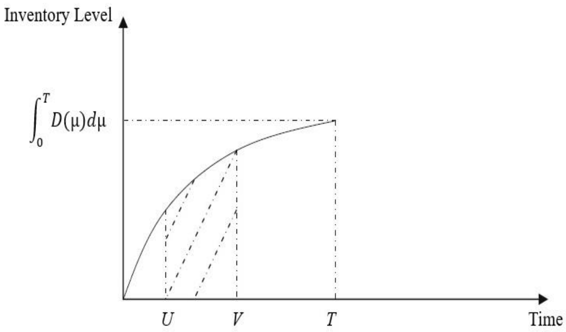


Figure 3. The total accumulation of interest earned when $V < T$

$$SV(T) = \begin{cases} SV_1(T), & 0 < T \leq U \\ SV_2(T), & U < T \leq V \\ SV_3(T), & V < T \end{cases} \qquad (4)$$

Where, $SV_j(T) = S_O + S_H + S_P + S_{Cj} - S_{Ej}$ j=1, 2, 3

On simplification, we get

$$SV_1(T) = \frac{1}{1-e^{-rT}} \left[A + \frac{h}{\theta} \left[\frac{(a-b+bT)(e^{\theta T} - e^{-rT})}{(\theta+r)} - \frac{(a-2b)(1-e^{-rT})}{r} + \frac{bTe^{-rT}}{r} \right] \right] + \frac{c}{\theta} \left[(a - b + bT)e^{\theta T} - (a - b) \right] - pI_e \left[\frac{(e^{-rU} - e^{-rV})}{r} \left(aT + \frac{bT^2}{2} \right) \right] \qquad (5)$$

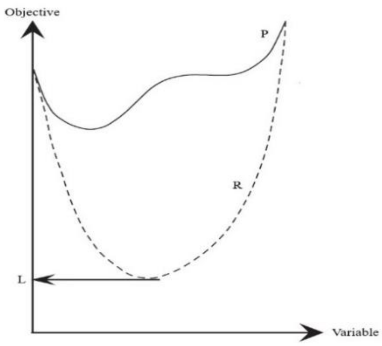
$$SV_2(T) = \frac{1}{1-e^{-rT}} \left[A + \frac{h}{\theta} \left[\frac{(a-b+bT)(e^{\theta T} - e^{-rT})}{(\theta+r)} - \frac{(a-2b)(1-e^{-rT})}{r} + \frac{bTe^{-rT}}{r} \right] + \frac{c}{\theta} \left[(a - b + bT)e^{\theta T} - (a - b) \right] - \frac{pI_e}{r} \left[(a + bT)e^{-rT} + a(U - 1)e^{-rU} + \frac{b(U^2 - U)e^{-rU}}{2} - e^{-rV} \left(aT + \frac{bT^2}{2} \right) \right] \right] \qquad (6)$$

$$SV_3(T) = \frac{1}{1-e^{-rT}} \left[A + \frac{h}{\theta} \left[\frac{(a-b+bT)(e^{\theta T} - e^{-rT})}{(\theta+r)} - \frac{(a-2b)(1-e^{-rT})}{r} + \frac{bTe^{-rT}}{r} \right] + \frac{c}{\theta} \left[(a - b + bT)e^{\theta T} - (a - b) \right] + cI_p \left[\frac{(a-b+bT)}{(\theta+r)} \left\{ \frac{\theta e^{-rT}}{r} + e^{\theta T} - \theta u - rV \right\} - \frac{(a-b+bV)e^{-rV}}{r} + \frac{b(e^{-rV} - e^{-rT})}{r} \right] - \frac{pI_e}{r} \left[\left\{ a(1 - V) + \frac{b(2V - V^2)}{2} \right\} e^{-rV} \right] \right] \qquad (7)$$

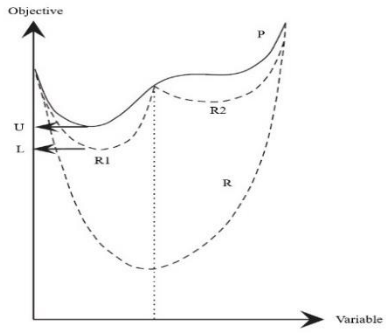
5. PROCEDURE FOR OPTIMAL SOLUTION

The Branch and Reduce Optimisation Navigator (BARON) in the GAMS software is used to solve the nonlinear programming (NLP) inventory models created in this study. To find the global optimum for a variety of issues, such as continuous, integer, nonlinear, and mixed-integer nonlinear problems, BARON uses branch-and-bound deterministic global optimisation methods. Although BARON was first identified as a technique for resolving combinatorial optimisation issues, it is being utilised for addressing broader multiextremal optimisation issues.

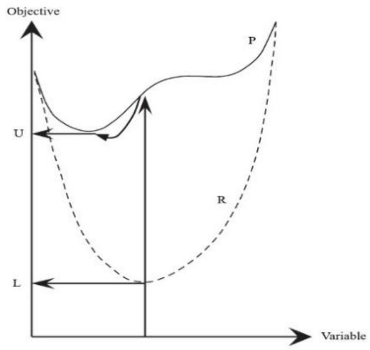
By building and solving its relaxation R over progressively refined partitions obtained by branching in the issue's feasible space, branch-and-bound solves an imagined problem P. The crucial methodology for this approach, which entails minimising a univariate function with two local minima, is shown in Figure 4. First, a problem relaxation (R) is formulated. Relaxed problem R is solved to obtain a lower constraint on the optimal objective function value of P, shown as L in Figure 4(a). Next, using further upper bounding heuristics and local minimization, an upper limit for the issue is produced, denoted by U in Figure 4(b). The process is finished and U is deemed the best option if the difference between U and L is negligibly tiny. If not, partition elements are created from the feasible region and added to open nodes that must be examined in order to identify the best solution and verify its globality. The next stage is to build a new relaxation based on the reduced size of a partition element that has been chosen from the open nodes. In order to guarantee that the algorithm still ends with a global optimum, domain reduction techniques are used to shrink and remove search regions (Figure 4(c)). As seen in Figure 4(d) [14], the branch-and-bound pro-cess is akin to a tree, with nodes standing in for boundaries and branches for the partitioning process. See [15] for additional details.



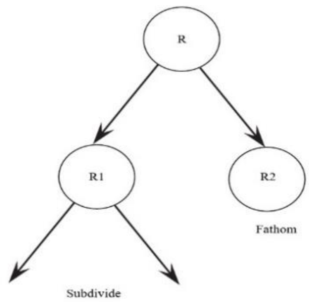
4.(a)



4.(c)



4.(b)



4.(d)

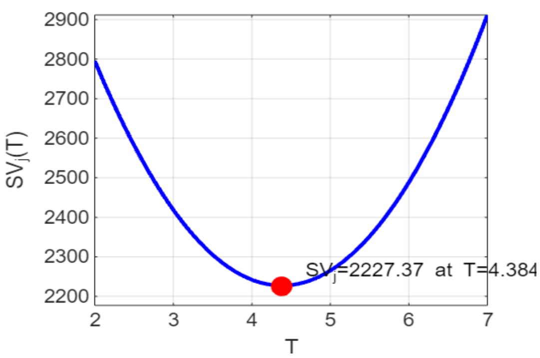


Figure 5. Convexity graph of $SV_J(T)$ with respect to T

6. NUMERICAL EXAMPLE AND SENSITIVITY ANALYSIS

There is an example to illustrate the proposed model. Let $A = \$2000$ per order, $\theta = 0.02$, $a = 100$, $b = 50$, $h = \$5$/unit/year, $p = \$5.5$ per unit, c= \$20 per unit, $I_e = 0.12$/\$/year, $I_p = 0.11$/\$/year, $V = 3$ months. Case-2: $U < T \leq V$ gives the optimal solution for the total cost. The optimal values are $T = 4.3845$ months, $U = 0.519358$ months and $SV(T) = 2227.37$ The optimal values of U and L which minimize the total cost function SV(T) are obtained by solving $\frac{\partial SV_j(T)}{\partial T} = 0$ and $\frac{\partial SV_j(T)}{\partial U} = 0$ by using MATLAB software.

The sensitivity analysis is performed using numerous parameters to investigate how the parameters affect the ideal solution. Table-2, Table-3, Table-4, Table-5 and Table-6, display the findings of the sensitivity analysis.

Parameter	Change in Parameter	T	U	$SV(T)$
V	3.1	4.2476	0.519359	4297.51
	3.2	4.2498	0.519350	4299.86
	3.3	4.2498	0.519342	4300.34
	3.4	4.2501	0.519337	4305.71
r	0.28	4.2215	0.638413	4315.24
	0.29	4.1037	0.596874	3631.83
	0.30	4.0081	0.540841	1907.31
	0.31	3.5894	0.501494	1103.54
θ	0.04	4.1333	0.519358	2208.67
	0.06	4.1448	0.519358	1004.81
	0.08	4.1565	0.519358	819.89
	0.10	4.1684	0.519358	697.27
A	110	4.2920	0.558034	4492.11
	120	4.3981	0.599687	4735.04
	130	4.3742	0.635862	4978.10
	140	4.4144	0.674961	5069.84
I_e	0.14	4.2488	0.519342	4297.46
	0.16	4.2518	0.519339	4299.45
	0.18	4.2549	0.519327	4301.46
	0.20	4.2579	0.519319	4303.45

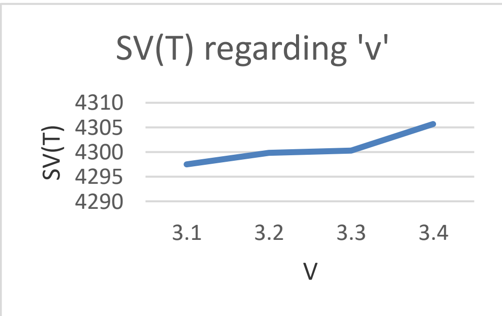


Figure 6. Change in SV(T) regarding ‘V’

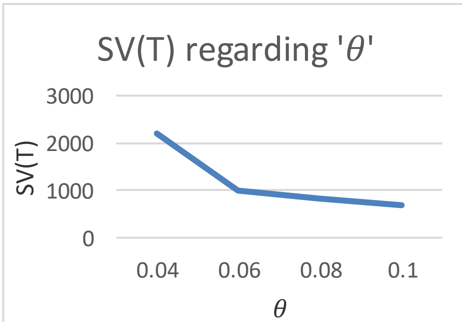


Figure 8. Change in SV(T) regarding ‘θ’

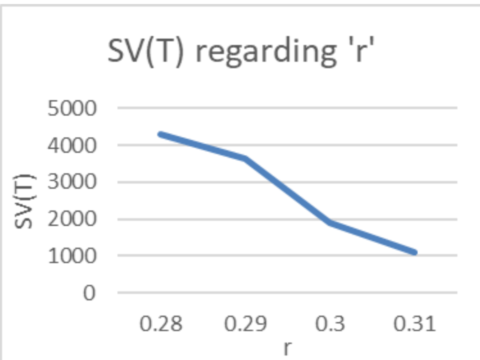


Figure 7. Change in SV(T) regarding ‘r’.

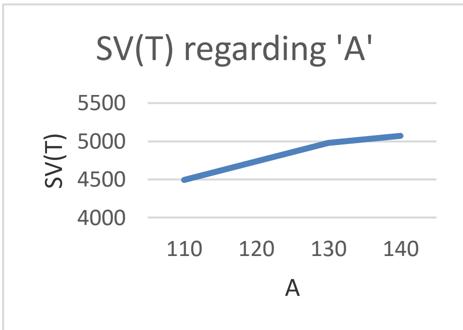


Figure 9. Change in SV(T) regarding ‘A’

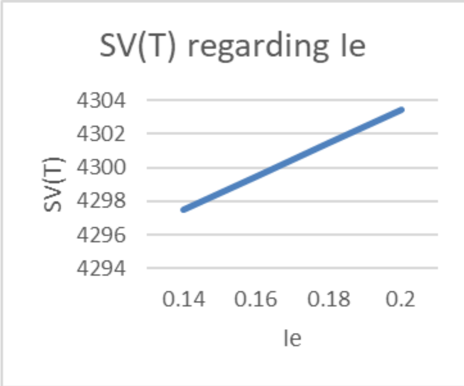


Figure 10. Change in SV(T) with I_e

7. OBSERVATIONS

i. Increasing the trade credit period (V) causes the model to undergo a series of adjustments. It results in a longer cycle length (T), a shorter acceptable delay supplied to customers (U), and an overall increase in the total cost function SV(T). This statement highlights the delicate balance that businesses must find between optimizing trade credit terms, sustaining client connections, and successfully controlling expenses.

ii. A rise in the discount rate (r) initiates a series of changes within the model. It results in a shorter cycle length (T) to reduce holding costs, a reduction in the length of acceptable delay supplied to consumers (U) as a result of increased cost concerns, and an overall decrease in the total cost function SV(T). This discovery emphasizes the importance of the discount rate as a factor influencing store inventory management decisions and cost-cutting measures.

iii. When the deterioration rate rises, the model responds by increasing the cycle length (T) to account for the increased deterioration-related losses. Because the duration of permitted delay (U) supplied to customers is unaffected by changes in the deterioration rate, it remains constant. The most noticeable consequence is a decrease in the total cost function SV(T), which is caused by the retailer's changes in ordering frequency and quantity to reduce the impact of deterioration-related costs.

iv. When demand parameter '*A*' rise, the model adjusts by increasing the cycle length (T) to accommodate greater order quantities, hence managing the increased demand. To synchronize cash flow with rising inventory needs, the merchant may additionally lengthen the period of permitted delay (U). However, due to greater inventory holding costs and potential cash flow issues, these adjustments contribute to an increase in the total cost function SV(T).

v. When interest earnings rise, the model responds by extending the cycle length (T) to capitalize on greater interest profits through lower holding costs. The maximum allowable delay (U) increases somewhat, allowing the merchant to better link cash flow with inventory management. Despite these changes, the total cost function SV(T) rises as a result of the interaction of longer cycle lengths, prospective holding cost increases, and cash flow considerations.

8. Managerial Insights

i. Through the provision of more accommodating payment terms, extending the trade credit period enhances client relations. Nevertheless, this results in a longer cycle time and a shorter acceptable delay for clients, raising total expenses (SV(T)). Managers must strike a balance between using credit to encourage client loyalty and putting plans in place to limit the ensuing cost rises. Optimizing inventory turnover and managing cash flow effectively are essential.

ii. A higher discount rate forces a shorter cycle length in order to minimize holding costs and lowers the amount of customer wait that is tolerable, which lowers overall costs (SV(T)). To take advantage of potential for cost savings, managers should routinely check discount rates and make adjustments to inventory regulations. Savings can be further increased by making strategic purchases and obtaining better terms with suppliers.

iii. Longer cycle lengths are necessary for higher deterioration rates in order to reduce deterioration-related losses, but the tolerable delay does not change. Overall costs are decreased by this modification (SV(T)). To lessen the effects of deterioration, managers should concentrate on lowering the frequency and volume of orders. Costs can be further decreased by making improvements to inventory turnover rates and investing in better storage options.

iv. Demand growth necessitates a longer cycle length in order to handle larger orders and may also lengthen the acceptable delay in order to balance inventory requirements with cash flow. But because of increased holding costs and possible cash flow problems, this raises overall costs (SV(T)). It is recommended that managers enhance their ability to estimate demand, optimize inventory levels, and guarantee adequate financial resources to effectively support rising demand.

v. Expanding the cycle duration to lower holding costs and somewhat raise the permitted delay to improve cash flow management are justified by higher interest earnings. Longer cycle lengths and higher holding costs could result in an increase in total costs (SV(T)) notwithstanding these modifications. To maximize profitability, managers should carefully balance the ad-vantages of higher interest earnings with cautious inventory and cash flow management.

9. CONCLUSION

In order to maximize retailer profit within a realistic market scenario containing predefined credit terms from suppliers and customers, this paper provides an inventory system for trended demand, where demand is linearly time-dependent. The importance of modifying inventory policies in response to higher discount rates to cut costs, the requirement for optimized inventory turnover in response to higher deterioration rates, and the necessity for managers to balance extended trade credit periods with cost control strategies due to increased overall costs (SV(T)) are some of the key findings. Increased customer demand also calls for better planning and forecasting to control rising costs, and higher interest rates force advantages to be balanced with inventory and cash flow management. The model highlights the crucial role that sensitivity analysis plays in identifying important factors, and it is supported by a numerical example. To further optimize inventory management and increase profitability, future study should include advanced demand forecasting, dynamic pricing, technological integration, sustainability practices, and the effects of global supply chain dynamics.

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