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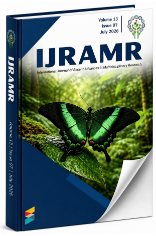

REVIEW ARTICLE

EOQ ANALYSIS FOR LINEARLY DETERIORATING ITEMS WITH LINEAR DEMAND AND TIME DEPENDENT PARTIAL BACKLOGGING

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ABSTRACT

This paper develops an Economic Order Quantity (EOQ) model that incorporates three realistic features of modern inventory systems: linear time-dependent demand, linear deterioration of stocked items, and a partial backlogging rate that varies with waiting time. Many traditional EOQ models assume constant demand and exponential deterioration, which limits their applicability to industries where consumption patterns grow steadily and items deteriorate at a proportional rate. To address this gap, the proposed model formulates a deterministic framework in which demand increases or decreases linearly over time, and deterioration is represented through a linear deterioration coefficient. Shortages are permitted, and the willingness of customers to wait is modelled as a decreasing function of the waiting time, leading to time-dependent partial backlogging. The total cost function is derived by combining ordering, holding, deterioration, and shortage-related costs and the optimal replenishment cycle and order quantity are obtained using analytical methods. A numerical example and sensitivity analysis highlight the influence of key parameters on the optimal policy. The findings demonstrate that time-dependent backlogging significantly affects shortage decisions, while linear demand and deterioration jointly shape replenishment frequency. The developed model offers practical insights for inventory managers dealing with gradually changing demand trends and products vulnerable to deterioration.

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INTRODUCTION

Inventory systems for deteriorating items have received extensive attention in recent years due to their relevance in sectors such as food processing, pharmaceuticals, chemicals, fashion goods, and technological components. Classical EOQ models often assume constant demand and neglect deterioration, thereby failing to capture the realistic behaviour of items whose quality degrades over time. In many industries, however, the demand pattern is time-dependent and can be represented effectively using a linear function, illustrating either a steady growth or decline in customer requirements. At the same time, deterioration may also progress linearly, particularly for products that lose usability, freshness, or effectiveness proportionally with storage duration. Another practical factor in inventory management is the nature of shortages. Although shortages are often unavoidable, customers differ in their willingness to wait for back-ordered items. In real markets, this willingness typically decreases as waiting time increases. This behaviour motivates the concept of time-dependent partial backlogging, in which only a fraction of unmet demand is backlogged, and this fraction diminishes with longer waiting times. This study integrates these three realistic aspects—linear demand, linear deterioration, and time-dependent partial backlogging—into a unified EOQ framework. The model incorporates deterioration loss, holding cost, shortage and backordering cost, and ordering cost to construct a comprehensive total cost function. By optimizing the cycle length and order quantity, the proposed approach provides inventory managers with an effective decision-making tool for conditions where both demand and product quality evolve linearly with time. Through numerical experimentation and sensitivity analysis, the research further illustrates how the interplay among demand rate, deterioration rate, and backlogging behaviour influences optimal inventory decisions.

LITERATURE REVIEW

Research on deteriorating inventory systems has progressed significantly, integrating various forms of demand structures, deterioration patterns, shortage conditions and financial considerations. Early contributions such as Mahata (2011) examined an

EOQ model incorporating exponential deterioration with a linearly increasing demand pattern under permissible delay in payments, highlighting how payment flexibility influences optimal order size. Similarly, Patel and Patel (2012) considered Weibull deterioration with linear demand, demonstrating that the interaction between time-dependent deterioration and trade-credit terms plays a crucial role in inventory decision-making. Further developments in the field address the complexity of shortages and backlogging behaviour. Singh and Pattnayak (2013) proposed an EOQ model with linear demand, variable deterioration, and partial backlogging, showing that the extent of backlogging significantly affects the cycle length and cost structure. This aligns well with studies such as Palanivel and Suganya (2021), who explored partial backlogging under-price and stock-dependent demand with time-varying holding cost and quantity discounts, indicating the growing emphasis on dynamic cost parameters and customer behaviour in shortages. In addition to shortage modelling, several researchers have examined the influence of demand drivers and price-related factors in deteriorating inventory systems. Mrudul et al. (2023) addressed price-sensitive demand and shortages under continuous compounding, providing insights into optimal pricing policies for deteriorating products. Udayakumar et al. (2020) extended this perspective by incorporating price- and advertisement-dependent demand along with deterioration and inflation, showing how market-driven demand plays a vital role in shaping replenishment policies. Likewise, Cardenas-Barron et al. (2020) investigated nonlinear stock-dependent demand and holding cost under trade credit, emphasizing the need for nonlinear modelling frameworks to represent real-world demand shifts accurately. The literature also reflects an increasing interest in operational constraints such as warehouse structure and supply chain environment. Kumar et al. (2024) analyzed a two-warehouse inventory model with time-dependent demand and preservation technology, underscoring how physical storage conditions and investment in preservation mitigate deterioration effects. Roy et al. (2020) introduced a two-warehouse probabilistic model with trade-credit and backorder discounts, illustrating how financial incentives influence backordering and procurement decisions. Jayaswal et al. (2021) studied deteriorating imperfect-quality items under learning and trade-credit financing, demonstrating the interplay between learning effects and inventory optimality.

Environmental and inflationary factors have also gained traction. Mashud et al. (2021) developed a sustainable inventory model incorporating controllable carbon emissions along with deterioration and advance payments, reflecting the shift toward integrating sustainability into inventory decisions. Sharma and Sharma (2022) examined how inflation, nonlinear holding costs, and nonlinear demand influence deteriorating inventory systems, showing that economic variability substantially impacts cost optimization.
Overall, the reviewed literature reveals extensive work on deteriorating inventory systems involving linear and nonlinear demand patterns, various forms of deterioration, partial backlogging, trade credit, and environmental considerations. While significant advancements have been made, the integration of linear demand, linear deterioration, and time-dependent partial backlogging within a unified EOQ framework remains less explored, highlighting the relevance and contribution of the present study.

ASSUMPTIONS AND NOTATIONS

Assumptions

- The model deals with a single type of item over a fixed and finite planning horizon, represented by T.
- Replenishment is assumed to be instantaneous, meaning that ordered items are received immediately without any lead time.
- The demand rate follows a linear function of time and is given by $D(t) = m + nt$ where m & n are constant coefficients representing the demand parameters.
- The deterioration rate at any time $t > 0$is modelled as a linearly time dependent function given by $\theta(t) = f + gt$ where $f > 0$ represents the initial deterioration rate and $g > 0$ denotes the rate of increase in deterioration over time.
- Shortages are allowed and during stock out period, the backlogging rate is variable and is dependent on the length of the waiting time for next replenishment, so that the backlogging rate is $B(t) = e^{-\delta(T-t)}$ where δ is the backlogging parameter such that 0<δ<1 and the parameter (T-t) is waiting time $t_1 \leq t \leq T$.
- The holding cost is assumed to remain constant throughout the cycle.

Notations

- $I_1(t)$ – Inventory level at time t for the interval$0 \leq t \leq t_1$.
- $I_2(t)$ – Inventory level at time t for the interval$t_1 \leq t \leq T$.
- Q – Quantity ordered in each cycle.
- W– Initial inventory level at the beginning of the cycle.
- T – Length of the entire inventory cycle.
- t_1 – Time period during which the available inventory is sufficient to satisfy demand
without any shortages
- C_o – Ordering cost per cycle
- C_p – Purchasing cost
- C_h – Holding cost
- C_d – Cost associated with deterioration
- C_S – Shortage cost for backordered items
- C_L – Cost corresponding to lost sales
- S – Backlog inventory level
- TC – Total cost per inventory cycle

MATHEMATICAL FORMULATION OF THE MODEL: At the start of each inventory cycle, a replenishment order of size Q is placed. Beginning with an initial stock level W, the inventory declines over the interval $[0, t_1]$due to both demand and deterioration, eventually reaching zero. Beyond this point, during the interval $[t_1, T]$, shortages occur as demand continues and a portion of the unmet demand is treated as partially backordered.

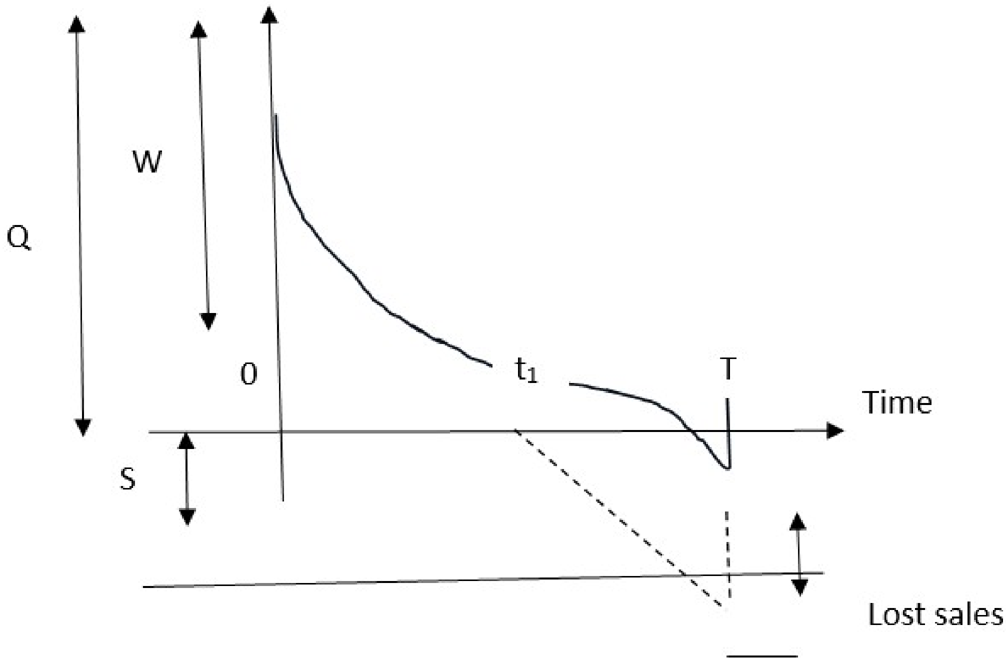

Figure 1. Representation of the inventory system

$$\frac{dI_1(t)}{dt} + (f + gt)I_1(t) = -(m + nt), \quad 0 \le t \le t_1 \tag{1}$$

This differential equation is solved underthe initial condition $I_1(0) = W$ and the terminal condition $I_1(t_1)=0$.
The solution to equation (1) is

$$I_1(t) = \frac{1}{\left(1+ft\ \frac{gt^2}{2}\right)}\left\{\begin{matrix} m(t_1 - t) + \frac{mf}{2}(t_1^2 - t^2) + \frac{mg}{6}(t_1^3 - t^3) + \frac{n}{2}(t_1^2 - t^2) + \frac{nf}{3}(t_1^3 - t^3) \\ + \ \frac{ng}{8}(t_1^4 - t^4) \end{matrix}\right\} \tag{2}$$

and

$$W = mt_1 + \frac{mf\ _1^2}{2} + \frac{mgt_1^3}{6} + \frac{nt_1^2}{2} + \frac{nf\ _1^3}{3} + \frac{ngt_1^4}{8} \tag{3}$$

During the interval from $t_1$to T, the system experiences shortages and a portion of the demand is partially backordered. Let $I_2(t)$represent the inventory level at any time $t$in this period. The rate of change of inventory in this interval is governed by the following differential equation:

$$\frac{dI_2(t)}{dt} = -(m + nt)e^{-\delta(T-t)}, \qquad t_1 \le t \le T \tag{4}$$

At time $t = t_1$, the inventory level is zero, which serves as the boundary condition:

$$I_2(t_1) = 0$$

The solution to equation (4) is

$$I_2(t) = m(1 - \delta T)(t_1 - t) + \frac{1}{2}(m\delta + n - n\delta T)(t_1^2 - t^2) + \frac{1}{3}n\delta(t_1^3 - t^3) \tag{5}$$

The maximum level of backordered inventory, denoted by □, occurs at the end of the cycle, i.e., at time $t = T$.

$$S = -I_2(T) = -[\, m(1 - \delta T)(t_1 - T) + \frac{1}{2}(m\delta + n - n\delta T)(t_1^2 - T^2) + \frac{1}{3}n\delta(t_1^3 - T^3)] \tag{6}$$

Consequently, the total quantity ordered over the entire time horizon [0,T] is:

$$\square = \square + \square$$

$$Q = mt_1 + \frac{mft_1^2}{2} + \frac{mgt_1^3}{6} + \frac{nt_1^2}{2} + \frac{nft_1^3}{3} + \frac{ngt_1^4}{8} - [\, m(1-\delta T)(t_1 - T) + \frac{1}{2}(m\delta + n - n\delta T)(t_1^2 - T^2) + \frac{1}{3}n\delta(t_1^3 - T^3)] \quad (7)$$

Ordering Cost (OC) = C_0

Purchase Cost (PC) = C_p Q

PC = $C_p\{mt_1 + \frac{mft_1^2}{2} + \frac{mgt_1^3}{6} + \frac{nt_1^2}{2} + \frac{nft_1^3}{3} + \frac{ngt_1^4}{8} - \left[m(1-\delta T)(t_1 - T) + \frac{1}{2}(m\delta + n - n\delta T)(t_1^2 - T^2) + \frac{1}{3}n\delta(t_1^3 - T^3)\right]\}$ (8)

Holding Cost (HC) = $\int_0^{t_1} C_h I_1(t)dt$

$$HC = C_h\{\frac{mt_1^2}{2} + t_1^3\left[\frac{mf}{6} + \frac{n}{3}\right] + t_1^4\left[\frac{mg}{12} - \frac{mf^2}{8} + \frac{nf}{8}\right] + t_1^5\left[\frac{ng}{30} - \frac{nf^2}{10} - \frac{mfg}{12}\right] + t_1^6\left[\frac{-7ngf - mg^2}{72}\right] - t_1^7\left[\frac{ng^2}{42}\right]\} \quad (9)$$

Deterioration Cost (DC) = $C_d\left\{W - \int_0^{t_1} D(t)dt\right\}$

$$DC = C_d\left\{\frac{mft_1^2}{2} + \frac{t_1^3}{3}\left(\frac{mg}{2} + nf\right) + \frac{ngt_1^4}{8}\right\} \quad (10)$$

Shortage Cost (SC) = $-C_s\int_{t_1}^{T} I_2(t)dt$

$$SC = -C_s\left\{mT(1-\delta T)\left(t_1 - \frac{T}{2}\right) + \frac{1}{2}T(m\delta + n - n\delta T)\left(t_1^2 - \frac{T^2}{3}\right) + \frac{1}{3}n\delta T\left(t_1^3 - \frac{T^3}{4}\right) - \frac{1}{2}mt_1^2(1-\delta T) - \frac{1}{3}t_1^3(m\delta + n - n\delta T) - \frac{1}{4}n\delta t_1^4\right\} \quad (11)$$

Lost Sales Cost (LSC) = $C_L\int_{t_1}^{T}\left[1 - e^{-\delta(T-t)}\right](m + nt)dt$

$$LSC = C_L\delta\left(\frac{mT^2}{2} + \frac{nT^3}{6} - mTt_1 - \frac{nTt_1^2}{2} + \frac{mt_1^2}{2} + \frac{nt_1^3}{3}\right) \quad (12)$$

Total cost (TC) = Ordering cost + Holding cost + Purchase cost + Deterioration cost

+ Shortage cost + Lost sales cost

$$= C_o + C_h\left\{\frac{mt_1^2}{2} + t_1^3\left[\frac{mf}{6} + \frac{n}{3}\right] + t_1^4\left[\frac{mg}{12} - \frac{mf^2}{8} + \frac{nf}{8}\right] + t_1^5\left[\frac{ng}{30} - \frac{nf^2}{10} - \frac{mfg}{12}\right] + t_1^6\left[\frac{-7ngf - mg^2}{72}\right] - t_1^7\left[\frac{ng^2}{42}\right]\right\} + C_p\left\{mt_1 + \frac{mft_1^2}{2} + \frac{mgt_1^3}{6} + \frac{nt_1^2}{2} + \frac{nft_1^3}{3} + \frac{ngt_1^4}{8} - \left[m(1-\delta T)(t_1 - T) + \frac{1}{2}(m\delta + n - n\delta T)(t_1^2 - T^2) + \frac{1}{3}n\delta(t_1^3 - T^3)\right]\right\} + C_d\left\{\frac{mft_1^2}{2} + \frac{t_1^3}{3}\left(\frac{mg}{2} + nf\right) + \frac{ng\,_1^4}{8}\right\} - C_s\left\{mT(1-\delta T)\left(t_1 - \frac{T}{2}\right) + \frac{1}{2}T(m\delta + n - n\delta T)\left(t_1^2 - \frac{T^2}{3}\right) + \frac{1}{3}n\delta T\left(t_1^3 - \frac{T^3}{4}\right) - \frac{1}{2}mt_1^2(1-\delta T) - \frac{1}{3}t_1^3(m\delta + n - n\delta T) - \frac{1}{4}n\delta t_1^4\right\} + C_L\delta\left(\frac{mT^2}{2} + \frac{nT^3}{6} - mTt_1 - \frac{nTt_1^2}{2} + \frac{mt_1^2}{2} + \frac{nt_1^3}{3}\right) \quad (13)$$

Our objective is to minimize the total cost.

The necessary condition is $\frac{\partial TC}{\partial t_1} = 0 \; and \; \frac{\partial^2 TC}{\partial {t_1}^2} > 0 \; for \; all \; t_1 > 0$

We get

$$\frac{\partial TC}{\partial t_1} = C_h\left\{mt_1 + 3t_1^2\left[\frac{mf}{6} + \frac{n}{3}\right] + 4t_1^3\left[\frac{mg}{12} - \frac{mf^2}{8} + \frac{nf}{8}\right] + 5t_1^4\left[\frac{ng}{30} - \frac{nf^2}{10} - \frac{mfg}{12}\right] + t_1^5\left[\frac{-7ngf - mg^2}{12}\right] - t_1^6\left[\frac{ng^2}{6}\right]\right\} + C_p\left\{m + mft_1 + \frac{mgt_1^2}{2} + nt_1 + nft_1^2 + \frac{ngt_1^3}{2} - m(1-\delta T) - (m\delta + n - n\delta T)t_1 - n\delta t_1^2\right\} + C_d\left\{mft_1 + t_1^2\left(\frac{mg}{2} + nf\right) + \frac{ngt_1^3}{2}\right\} - C_s\{mT(1-\delta T) + Tt_1(m\delta + n - n\delta T) + n\delta Tt_1^2 - mt_1(1-\delta T) - t_1^2(m\delta + n - n\delta T) - n\delta t_1^3\} + C_L\delta(-mT - nTt_1 + mt_1 + nt_1^2) \quad (14)$$

and

$$\frac{\partial^2 TC}{\partial {t_1}^2} = C_h\left\{m + 6t_1\left[\frac{mf}{6} + \frac{n}{3}\right] + 12t_1^2\left[\frac{mg}{12} - \frac{mf^2}{8} + \frac{nf}{8}\right] + 20t_1^3\left[\frac{ng}{30} - \frac{nf^2}{10} - \frac{mfg}{12}\right] + 5t_1^4\left[\frac{-7ngf - mg^2}{12}\right] - t_1^5 ng^2\right\} + C_p\left\{mf + mgt_1 + n + 2nft_1 + \frac{3ngt_1^2}{2} - (m\delta + n - n\delta T) - 2n\delta t_1\right\} + C_d\left\{mf + 2t_1\left(\frac{mg}{2} + nf\right) + \frac{3ngt_1^2}{2}\right\} - C_s\{T(m\delta + n - n\delta T) + 2n\delta Tt_1 - m(1-\delta T) - 2t_1(m\delta + n - n\delta T) - 3n\delta t_1^2\} + C_L\delta(-nT + m + 2nt_1) \quad (15)$$

NUMERICAL EXAMPLE: Let us consider an inventory system with the following parameter values:

$m = 200, n = 100, f = 0.5, g = 1.5, T = 2, \delta = 0.03, C_h = 1, C_p = 3, C_d = 0.2,$
$C_s = 12, C_L = 10, C_o = 60.$

Then we get $t_1 = 1.4320, Q = 975.4170, TC = 3986.1$

SENSITIVITY ANALYSIS

The sensitivity analysis investigates how variations in key parameters affect the optimal decisions within the EOQ model for linearly deteriorating items under linear demand and time-dependent partial backlogging.By varying each parameter individually while keeping all others constant, the analysis reveals how the system behaves when subjected to fluctuations in baseline demand, demand growth, initial deterioration, deterioration acceleration and customer backordering tendencies. The resulting changes in the shortage-free period, optimal order quantity and total cost provide a clear understanding of the parameters that significantly influence inventory performance. This evaluation not only demonstrates the robustness of the model but also offers practical insights for decision-makers in adjusting replenishment policies under dynamic and uncertain conditions. Overall, the sensitivity analysis confirms that effective inventory management requires careful attention to demand and deterioration patterns, as well as customer responses to shortages.

Table – 1: Variation in m

m	t_1	Q	TC
180	1.4367	914.0318	3727.0
190	1.4343	944.7059	3856.6
200	1.4320	975.4170	3986.1
210	1.4299	1006.2	4115.7
220	1.4280	1036.9	4245.2

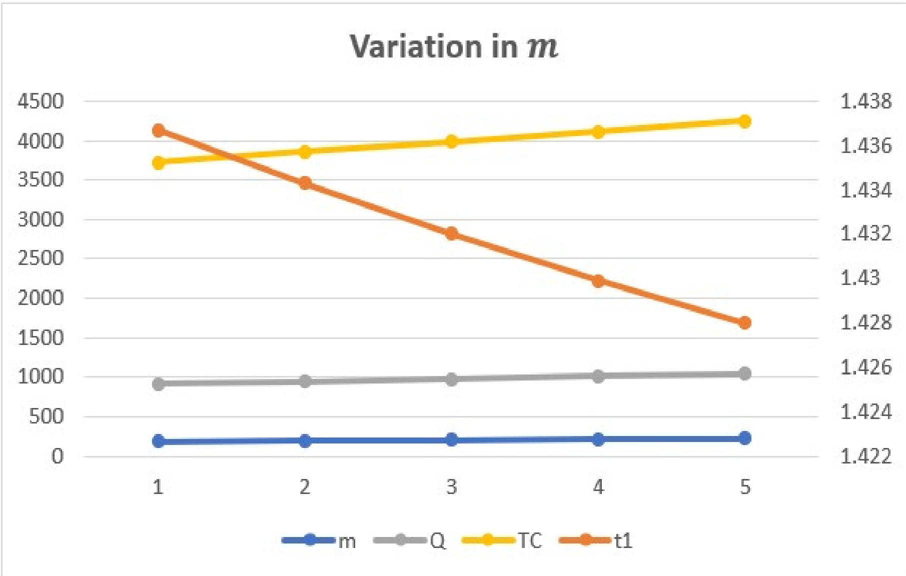

Table 1 examines the effect of changes in the demand parameter m on key inventory measures when demand follows $D(t) = m + nt$and deterioration is time-dependent as $\theta(t) = f + gt$. As $m$increases, the initial demand level rises, causing inventory to deplete more rapidly. Consequently, the shortage-free period$t_1$shows a slight decrease. To satisfy the higher baseline demand, the system requires a larger replenishment, leading to a steady increase in the optimal order quantity (Q). This rise in$Q$, combined with the stronger demand pressure, results in a continuous increase in the total cost (TC). Thus, higher values of$m$ make the system more costly and require larger inventory investment.

Table – 2: Variation in n

n	t_1	Q	TC
80	1.4229	903.5162	3719.0
90	1.4276	939.3978	3852.6
100	1.4320	975.4170	3986.1
110	1.4363	1011.6	4119.6
120	1.4403	1047.8	4253.0

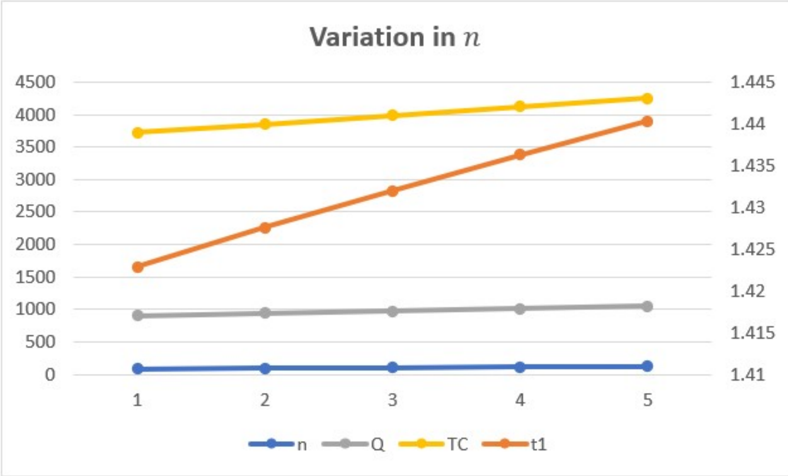

Table 2 shows the impact of changes in the demand growth parameter$n$ on the system's performance. Since demand is given by $D(t) = m + nt$, increasing n makes demand rise more rapidly over time. As $n$increases, the inventory depletes faster during the cycle, causing the system to require more inventory overall. This results in a gradual increase in theshortage-free period$t_1$as the system adjusts to accommodate the accelerated demand pattern. The optimal order quantity (Q) also increases steadily because higher time-dependent demand necessitates larger replenishment to avoid shortages. This higher demand intensity raises operational costs, leading to a consistent increase in the total cost (TC). Overall, variations in$n$show that a faster-growing demand rate significantly elevates both order size and total cost in the system.

Table – 3. Variation in f

f	t_1	Q	TC
0.3	1.4508	927.7891	3843.0
0.4	1.4407	951.5235	3916.5
0.5	1.4320	975.4170	3986.1
0.6	1.4247	999.7075	4052.2
0.7	1.4190	1024.7	4114.8

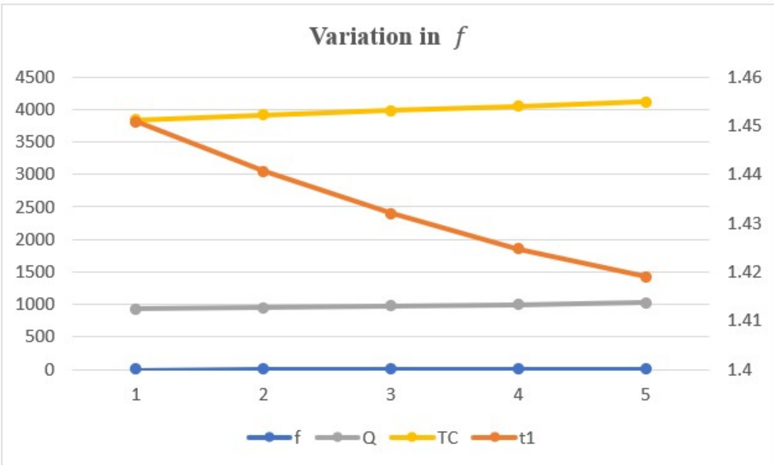

Table 3 analyzes how the system responds to changes in the baseline deterioration rate$f$in the deterioration function $\theta(t) = f + gt$. As $f$increases, the initial level of deterioration becomes higher, causing inventory to spoil at a faster rate from the beginning of the cycle. Due to this increased deterioration pressure, the shortage-free period$t_1$gradually decreases because usable stock depletes sooner. At the same time, higher deterioration compels the system to order more units to compensate for the increased loss of inventory, resulting in a steady increase in the optimal order quantity (Q). This additional replenishment requirement, combined with elevated deterioration-induced losses, leads to a consistent rise in the total cost (TC). Overall, an increase in $f$makes the system more deterioration-sensitive, reducing effective inventory time and raising operational expenses.

Table 4. Variation in g

□	□$_1$	□	□□
1.3	1.4468	955.9366	3919.6
1.4	1.4391	965.6538	3953.5
1.5	1.4320	975.4170	3986.1
1.6	1.4256	985.2829	4017.5
1.7	1.4199	995.3146	4047.6

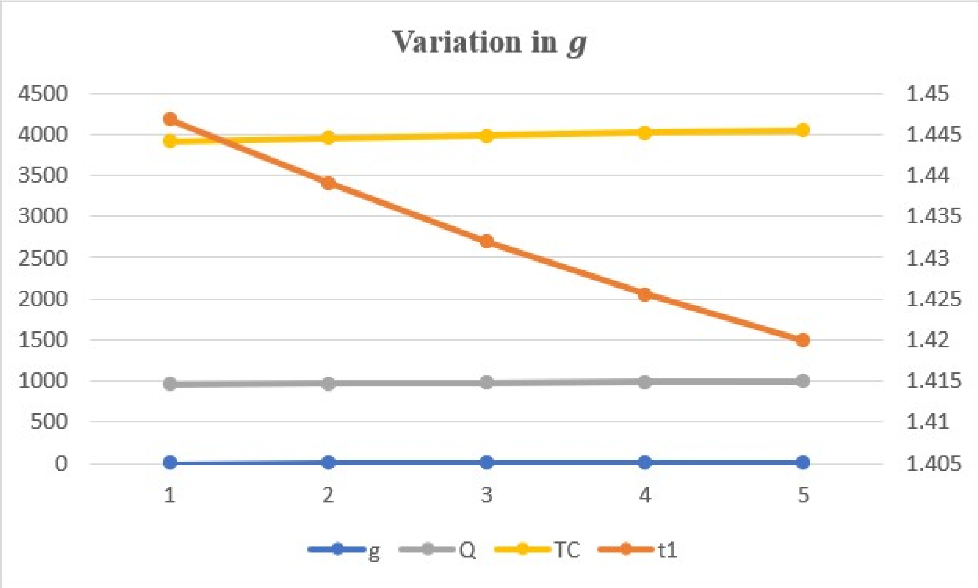

Table 4 examines the effect of changes in the deterioration growth parameter$g$on the inventory system. Since deterioration increases with time according to $\theta(t) = f + gt$, a higher value of$g$ means that the rate of deterioration accelerates more rapidly as time progresses. Asg increases, inventory spoils faster during the cycle, causing the available stock to diminish earlier. This results in a steady decrease in the shortage-free periodt_1, as the system reaches the point of replenishment sooner. To compensate for the faster deterioration, the system must order a larger quantity of items, leading to a consistent increase in the optimal order quantity (Q). The combined effect of higher replenishment needs and greater deterioration losses contributes to a continuous rise inthe total cost (TC). Thus, higher values of $g$make the inventory system more sensitive to time-dependent deterioration, increasing both order size and overall operational costs.

Table 5. Variation in δ

δ	t_1	Q	TC
0.01	1.4319	976.4650	3983.2
0.03	1.4320	975.4170	3986.1
0.05	1.4322	974.3727	3989.1
0.07	1.4324	973.3322	3992.0
0.09	1.4325	972.2957	3995.0

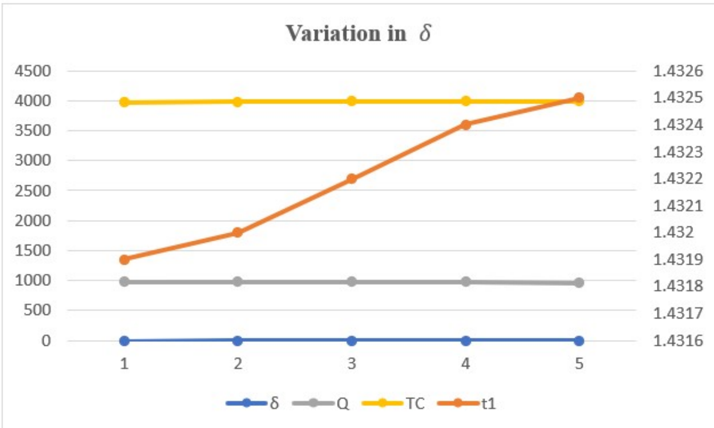

Table 5 presents the effect of changes in the backlog parameterδ, which determines the responsiveness of customers to waiting during a shortage period. A higher value of δ represents a stronger tendency for customers to backorder rather than abandon demand. As δincreases, the shortage is more easily tolerated, allowing the system to extend the cycle slightly. This results in a small increase in the shortage-free periodt_1. Since more demand can be postponed to the backordering period, the system does not need to order as many units during replenishment. Consequently, the optimal order quantity (Q) decreases gradually as δ increases. However, the increased reliance on backordering and the extended cycle introduce additional costs, leading to a steady increase in the total cost(TC). Overall, higher values of δ make backordering more attractive, allowing a longer cycle and lower order quantity but at the expense of increased total cost.

CONCLUSION

This paper presents a deterministic EOQ model that jointly considers linear demand, linear deterioration, and time-dependent partial backlogging, offering a more realistic representation of inventory systems handling perishable or degradable items. The formulation captures the dynamic nature of demand and deterioration and incorporates customer waiting behaviour through a time-dependent backlogging component. Analytical results, supported by numerical evaluation, show that replenishment decisions are sensitive to changes in deterioration and demand growth, while the backlogging function plays a crucial role in determining the severity and duration of shortages. The model demonstrates that adopting time-dependent partial backlogging results in more accurate and cost-effective inventory policies compared to traditional constant-backlogging assumptions. The research contributes a flexible decision-support tool for practitioners and provides a foundation for further extensions involving price-dependent demand, multi-warehouse structures, preservation investment, and stochastic deterioration.

MANAGERIAL IMPLICATIONS

The proposed EOQ model offers several practical insights for inventory managers overseeing products whose demand and deterioration evolve steadily over time. Since both demand and deterioration follow linear trends, the optimal replenishment cycle is highly sensitive to changes in these rates. Managers should adjust order frequency based on the observed direction and intensity of the demand slope and deterioration rate. When demand grows rapidly or items deteriorate quickly, shorter cycles with smaller order sizes help minimize spoilage and excess holding costs. Conversely, in environments with stable demand and slower deterioration, longer replenishment cycles remain cost-effective. The model also highlights the strategic role of customer waiting behaviour. Time-dependent partial backlogging demonstrates that customers become less willing to wait as shortage duration increases. By improving communication, offering delivery updates, or providing small incentives, firms can increase the fraction of backlogged demand and reduce costly lost sales. This insight allows managers to treat shortage-handling as a service-design decision rather than an unavoidable cost. Additionally, segmenting products by perishability and customer patience enables tailored replenishment policies, where highly perishable and low-patience items receive priority scheduling, while long-life items with patient customers follow longer cycles. Finally, this study emphasizes the importance of regularly updating key parameters such as demand trend, deterioration rate and backlogging sensitivity. Small deviations in these values can alter optimal decisions, making periodic calibration essential for real-world use. Managers should complement the model with scenario or sensitivity analyses to understand how cost and service performance change under different operational conditions. The resulting framework equips firms to make informed, cost-effective decisions that balance order frequency, deterioration losses, customer satisfaction and shortage risk.

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