



RESEARCH PAPER

An Integrative Analysis of Deterioration and Backlogging Strategies in Modern Inventory Management: A Synthesis of Demand Dynamics

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Abstract

The dynamic demand conditions of perishable goods that need to be managed by inventory management necessitate complex mathematical modeling to make the operations efficient. In this paper, an integrative model of inventory systems that experience wear and demand fluctuations is created. Combining trapezoidal and price-sensitive demand dynamics with the usage of fractional backlogging mechanisms, we develop an abstracted cost minimization model. The governing differential equations in the inventory levels are obtained and an example is used to show the effect of the rates of deterioration and the rate of backlogging on the overall costs of the system. The findings highlight the importance of matching the replenishment policies with the physical product depreciation and consumer waiting to attain economic sustainability in the supply chain context.

KEYWORDS:

Decaying Inventory, Trapezoidal Demand, Fractional Backlogging, Price Sensitivity, Inventory Modeling, EOQ.

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Introduction

The classical Economic order quantity (EOQ) model, which was devised by Harris (1913) and popularized by Wilson (1934), makes the assumption of constant demand and an infinity shelf life- conditions that are seldom met in the modern supply chain. The exponential decay function that was introduced by Ghare and Schrader (1963) became the basis of the current modern perishable goods management by modeling a deteriorating inventory. In a seasonally fluctuating demand or a demand that is price sensitive, as observed by Goyal and Giri (2001), the mathematical complexity of the inventory systems is

greatly enhanced. Scholars have then come up with deterministic and stochastic models to reflect physical wear and tear (Shah and Shah, 2000), trapezoidal demand lifecycle sequences (Skouri et al., 2009), and consumer back-logging behavior in times of stock-out (Padmanabhan and Vrat, 1995). This article combines these streams so as to create a coherent analytical framework.

2. Dynamics and Deterioration of Demand

The demand rate constitutes a fundamental element of inventory control theory. Trapezoidal demand effectively



captures product lifecycle phases: initial market growth, maturity saturation, and eventual decline. Sharma (2015) utilized this pattern for deteriorating inventory models, demonstrating its applicability to seasonal products [1]. The physical condition of inventory necessitates explicit deterioration modeling; as Sharma (2019) emphasizes, the majority of physical products experience spoilage, obsolescence, or degradation during storage [5]. Mathematically, let $I(t)$ denote the inventory level at time t . The inventory depletes due to both demand and deterioration. For an item with constant deterioration rate θ and trapezoidal demand rate $D(t)$ defined as:

$$D(t) = \begin{cases} a + bt & 0 \leq t \leq t_1 \\ D_{\max} & t_1 \leq t \leq t_2 \\ a' - b't & t_2 \leq t \leq T \end{cases}$$

the governing differential equation during the positive inventory period is:

$$\frac{dI(t)}{dt} + \theta I(t) = -D(t), \quad I(0) = Q, \quad I(t_3) = 0$$

Where Q represents the order quantity and t_3 denotes the time of stock depletion.

4. Historical Evolution and Uniform Demand Foundations

Simple equations of EOQ have developed into complex systems of differential equations known as inventory modeling. The early models were generalized by Whitin (1957) to include deteriorating fashion goods, and by Covert and Philip (1973) to Weibull distributions. The

6. Conclusion

Combination of trapezoidal demand, fractional backlogging and demand sensitive order rate is the frontier of inventory science. By matching the rates of deterioration with strategic limits of backlogging, organizations reduce financial risks of overstocking and stock-outs. The quantitative analysis shows that the parameters of

3. Backlogging and Pricing Strategies

Shortage management critically influences the profitability when demand exceeds available stock. Sharma and Bansal (2016) examined inventory models incorporating time-dependent demand through fractional backlogging, where only a proportion $\beta(x)$ of customers wait for replenishment, with x representing the waiting time [2]. The backlogging rate typically follows:

$$\beta(x) = \frac{1}{1 + \delta x}, \quad \delta > 0$$

Where δ denotes the customer impatience parameter.

So, For price-sensitive demand, let p represent the unit selling price. The price-dependent demand rate follows $D(p) = \alpha - \beta p$ ($\alpha, \beta > 0$). Sharma (2020) demonstrated that fixed deterioration models must incorporate such demand functions to reflect market realities [3]. Introducing limited backlogging into these models enables firms to quantify the trade-off between pricing power and permanent customer loss during shortages. The total cost function TC per cycle integrates ordering cost C_o , holding cost C_h , deterioration cost C_d , shortage cost C_s , and lost sales cost C_l :

$$TC = C_o + C_h \int_0^{t_3} I(t) dt + C_d \theta \int_0^{t_3} I(t) dt + C_s \int_{t_3}^T [-I(t)] dt + C_l \int_{t_3}^T D(p)[1 - \beta(x)] dt$$

time-based homogenous demand is still basic in benchmarking the complex variations [4]. The knowledge of these underlying models can help researchers to create multi-disciplinary solutions to the modern supply chain issues, such as stochastic lead times and inflationary impacts (Buzacott, 1975; Misra, 1979).

deterioration have significant impact on the total costs and its estimation should be accurate in practice. The theoretical aspect of mathematical modeling and empirical data of logistics that should be bridged in future studies include stochastic demand and multi-echelon structure of supply chain.

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