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ANALYSIS OF INVENTORY MODEL WITH TIME DEPENDENT DEMAND UNDER FRACTIONAL BACKLOGGING

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ABSTRACT: Deterioration of physical goods in stock is very realistic feature of inventory control because there are many goods that either deteriorate or obsolete in the course of time. Deterioration rate of any item is either constant or time dependent. When deterioration is time dependent, time is accompanied by proportional loss in the value of the product. Realization of this factor motivated modelers to consider the deterioration factor as one of the modeling aspects. In practice, the stock-out cost can be easy to obtain from accounting data. However, such a situation can be seen to occur in a case where customers are loyal enough to wait until a fresh lot arrives during the stock-out period. Their definitions of backlogging rate discussed above seem to be inappropriate under some circumstances. In reality, often some customers are conditioned to a shipping delay, and may be willing to wait for a short time, while others will leave for another seller because of their urgent need. Therefore, the length of the waiting time until the next replenishment is the main factor for deciding whether the backlogging will be accepted or not.

KEYWORDS: Deterioration, backlogging

INTRODUCTION

Inventory is the idle resource of an enterprise. Although idle, a certain amount of inventory is essential for smooth running of an organization. In a manufacturing or process industry, non-availability of a critical raw material may result in a closure of the plant. In a service-oriented organization such as a State Transport Corporation, absence of a spare part when it is required will affect the maintenance of vehicles as a result of which the quality of service will deteriorate. Inventory refers to the physical stock of goods which, though remains idle in a store, is essential for operational convenience. Inventory is simply a stock of physical assets having some economic value, which can be either in the form of material, money or labor. Inventory is also known as an idle resource as long as it is not utilized.

Inventory is any stored resource that is used to satisfy a current or a future need. Raw materials, work in process and finished goods are examples of inventory. Inventory levels for finished goods are a direct function of demand. When determine the demand for completed clothes dryers, for example, it is possible to use this information to determine how much sheet metal, paint, electric motors, switches and other raw materials and work in process are needed to produce the finished product.

FRACTIONAL BACKLOGGING

A supply chain system in which a supplier prepares for the selling season by building stock levels prior to the beginning of the season and shortages realized at the beginning of the season are represented as mixtures of backorders and lost sales. The many real-life situations, the practical experiences reveal that some but not all customers will wait for backlogged items during a shortage period, such as for fashionable commodities or high-tech products with short product life cycle. The longer the waiting time is, the smaller the backlogging rate would be. According to such phenomenon, taking the backlogging rate into account is necessary.

Order Level: The level of stock of any item at which an order is initiated for more supplies of that item.

Delivery Leg or Lead Time: The time between the requisition for an item and its receipt is known as delivery lag or lead time. In general, the lead time may be deterministic or probabilistic having following four components:

1. Administrative lead time – can be fixed in nature,
2. Supplier's lead time – can be fixed in nature,
3. Transportation lead time – cannot be fixed, and
4. Inspection lead time – cannot be fixed.

Safety stock: Safety stock is a term used by inventory specialists to describe a level of extra stock that is maintained below the cycle stock to buffer against stock outs. Safety Stock (also called Buffer Stock) exists to counter uncertainties in supply and demand. Safety stock is defined as extra units of inventory carried as protection against possible stock outs (shortfall in raw material or packaging). By having an adequate amount of safety stock on hand, a company can meet a sales demand which exceeds the demand they forecasted without altering their production plan. It is held when an organization cannot accurately predict demand and/or lead time for the product. It serves as an insurance against stock outs.

Quantity Discount and Order Quantity: Form of an economic order quantity (EOQ) model that takes into account quantity discounts. Quantity discounts are price reductions designed to induce large orders. If quantity discounts are offered, the buyer must weigh the potential benefits of reduced purchase price and fewer orders against the increase in carrying costs caused by higher average inventories. Hence, the buyer's goal in this case is to select the order quantity that will minimize total costs, where total cost is the sum of carrying cost, ordering cost, and purchase cost.

It is a common business practice for pricing schedule to display economies of scale with prices decreasing as lot size increases. Such pricing schedules offer discounts based on the quantity ordered in a single lot. This encourages the retailers to order in larger lots to take advantage of price discounts. This adds to the average inventory and flow time in a supply chain. Unlike the EOQ model, the purchase cost now becomes an important criterion in determining the optimal order size and the corresponding total annual inventory cost.

For example, there are some essential commodities for which a competitive market exists and costs are driven down to the products' marginal cost. In this case, market sets the price and the firm's objective is to lower the costs. Here, the manufacturers with large fixed costs per lot can use lot-size based quantity discounts to maximize the overall profits. Lot size based discounts however, increase the cycle inventories.

Sometimes, manufacturers use trade promotions to increase sales by offering a discounted price over a pre specified period of time over which the discount is effective. In some cases, the manufacturer may require some specific actions from the retailer to qualify for the discount, such as, displays, advertising, promotion, and so on. Trade promotions are quite common in the consumer packaged goods industry, with manufacturers promoting different things at different times of the year. The goal of the trade promotions is to influence retailers to act in a way that helps the manufacturer achieve its goal.

Time horizon: This refers to the planning period over which inventory is to be controlled. The planning period may be finite or infinite. In general, inventory planning is carried out on annual basis. If the time period is long, the time value of cost should be taken into consideration using proper discount factors. On the other hand, it is also possible that the item can be stored only for a limited time period due to perishability or obsolescence. The model should, therefore, minimize the cost over the specific period of time.

Deterioration: In the inventory management, the decay of the items plays an important role. In reality, some of the items are either damaged or decayed or vaporized or affected by some other factors, i.e. these are not in a perfect condition to satisfy the demand. The rate of the deterioration of an item is either constant, time dependent or stock dependent. Some items which are made of glass, China clay or ceramic break during their storage period for which the deterioration rate depends upon the size of the total inventory. The decaying item such as photographic film, electronic goods, fruits and vegetables gradually loose their utility with time. Deterioration is defined as change, damage, decay, spoilage, evaporation, obsolescence, pilferage, and loss of utility or loss of marginal value of a commodity that results in decreasing usefulness from the original one. Most products such as medicine, blood, fish, alcohol, gasoline, vegetables and radioactive chemicals have finite shelf life, and start to deteriorate once they are replenished.

Trade credit : The traditional economic order quantity (EOQ) model focuses on the buyer's view and makes several assumptions, for example, no stock-outs, fixed demand rate, unlimited store space, zero lead time and must be paid for the items as soon as the items were received. But we know these assumptions are rarely met in real-life situation. For instance, in most business transactions, the supplier would allow a specified credit period (say, 30 days) to the retailer for payment without penalty to stimulate the demand of his/her products. This credit term in financial management is denoted as "net 30." Before the end of the trade credit period, the retailer can sell the goods and accumulate revenue and earn interest.

Inflation: In economics, inflation is a rise in the general level of prices of goods and services in an economy over a period of time. When the price level rises, each unit of currency buys fewer goods and services; consequently, inflation is also erosion in the purchasing power of money – a loss of real value in the internal medium of exchange and unit of account in the economy. A chief measure of price inflation is the inflation rate, the annualized percentage change in a general price index (normally the Consumer Price Index) over time.

Inflation can have many effects that can simultaneously have positive and negative effects on an economy. Negative effects of inflation include a decrease in the real value of money and other monetary items over time; uncertainty about future inflation may discourage investment and saving, or may lead to reductions in investment of productive capital and increase savings in non-producing assets. e.g. selling stocks and buying gold. This can reduce overall economic productivity rates, as the capital required to retool companies becomes more elusive or expensive. High inflation may lead to shortages of goods if consumers begin hoarding out of concern that prices will increase in the future. Positive effects include a mitigation of economic recessions, and debt relief by reducing the real level of debt.

Economists generally agree that high rates of inflation and hyperinflation are caused by an excessive growth of the money supply. Views on which factors determine low to moderate rates of inflation are more varied. Low or moderate inflation may be attributed to fluctuations in real demand for goods and services, or changes in available supplies such as during scarcities, as well as to growth in the money supply. However, the consensus view is that a long sustained period of inflation is caused by money supply growing faster than the rate of economic growth.

Today, most mainstream economists favor a low steady rate of inflation. Low (as opposed to zero or negative) inflation may reduce the severity of economic recessions by enabling the labor market to adjust more quickly in a downturn, and reduce the risk that a liquidity trap prevents monetary policy from stabilizing the economy. The task of keeping the rate of inflation low and stable is usually given to monetary authorities. Generally, these monetary authorities are the central banks that control the size of the money supply through the setting of interest rates, through open market operations, and through the setting of banking reserve requirements.

Warehouse: A warehouse is a location with adequate facilities where volume shipments are received from a production centre, broken order or orders, and shipped to the customer's location or locations. The rationale for establishing a warehouse in a distribution network is the creation of a differential advantage for the firm.

The concept of a distribution warehouse or a distribution centre is vastly different from the earlier concept of a godown for storage. The godown is merely a dumping place. Godowns are maintained merely for storage of surplus place. The earlier concept, which led to the establishment of warehouses, was based on the need for ensuring a continuous, uninterrupted supply of goods in the market area for the following:

- Ensuring protection against delays and uncertainties in transportation arising from a variety of factors;
- Eliminating lack of sophistication in production control and consequent uncertainties in the availabilities of product at the desired time and place;
- Providing for adjustment between the time of production and the time of use because production and use can be synchronized;
- Serving as a reservoir of goods, receiving surplus goods when production exceeds demand and releasing in anticipated.

From the foregoing, it is obvious that earlier a warehouse considered a necessary evil which was to be tolerated, but which did little to provide a differential advantage. The modern distribution centre or distribution warehouse is a pivot in the physical distribution system. According to this system, movement is the primary objective of a warehouse. As per this new concept, a warehouse is a location where inputs (incoming factory shipments) are converted into outputs (outputs shipments representing orders of customers). This conversion takes place without consuming too much time. The goods may be received over a period of time from different places, combined or broken down into each individual customer's orders, and dispatched to the next point in the distribution channel without their coming rest within the confines of the distribution centre. Because of the usual and often inevitable lack of co-ordination between inbound and outbound goods, storage facilities of a temporary nature must be provided for in the scheme. However, the distribution centre continues to be a dynamic location in which flow is accentuating and where storage, with its static connotation, is a facilitating function os secondary importance. Conceptually, the distribution centre is not unlike a retail store in its interactions with its customers.

Mathematical Modelling: A mathematical model uses mathematical language to describe a system. The process of developing a mathematical model is termed **mathematical modelling** (also modeling). Mathematical models are used not only in the natural sciences (such as physics, biology, earth science, meteorology) and engineering disciplines, but also in the social sciences (such as economics, psychology, sociology and political science); physicists, engineers, computer scientists, and economists use mathematical models most extensively. Model is defined as idealized representation or an abstraction of some real-life system, whether such system refers to a problem, process, operation, object or events. The objective of the model is to provide a means for analyzing the behavior of the system for the purpose of improving its performance or, if the system is not in the existence, to define the ideal structure of this future system indicating the functional relationships among its elements. By building a model, the complexities and uncertainties of a decision-makers problem can be changed to a logical structure that is amendable to formal analysis. Such a model specifies the decision alternatives and their anticipated consequences for all possible events that may occur, indicates the relevant data for analyzing the alternatives, and leads to meaningful and informative managerial conclusions. In short, modeling is a means of providing a clear structural frame-work to the problem for purpose of understanding and dealing with reality.

REVIEW OF LITERATURE

Chung [2009] et al considered an inventory model with imperfect quality items under the condition of two warehouses for storing items. A detailed survey of the recent inventory models with imperfect items are provided by Khan et al. [2011]. Mukhopadhyay and Goswami [2013] developed an inventory model for imperfect items with exponentially decreasing time varying demand and constant deterioration where shortages were fractionally backlogged.

Learning phenomena cannot be ommit. By monitoring demand, shortage, holding cost & backlogged we can improve results as well as performance, shortage cannot be vanish. While developing inventory model we have to improve effective tools and machinery, production procedure, human resource environment. Learning, shortage and backlogging, we have developed a new effective inventory model. The learning phenomena defined by Wright [1936]. Jordan [1958] formulated that how to use the learning curve. An EPQ model under learning effect was developed by Fisk and Ballou [1985]. Balkhi [2003] analyzed an optimal production lot size for deteriorating items with learning effect. An inventory model for imperfect quality items with learning was introduced by Jaber et. al. (2008). Kumar et al. (2013) investigated a Learning effect on an inventory model with two-level storage and fractional backlogging. An imperfect quality items with learning under two limited storage capacity was developed by Singh et.al. (2013). Singhal & Singh (2015) proposed an inventory system with multi variate demand under volume flexibility and learning.

AlSalamah and Alsawafy [2012] considered an EOQ model with two types of imperfect items and obtained the optimal policy that maximizes the total profit. They found that lot size increases with the increase in the fraction of scrap items and re-workable item but expected total profit decreases. Mukhopadhyay and Goswami [2013] developed an inventory model for imperfect items when demand followed time varying linear pattern. The cost minimization optimal policy was considered by Tsou [2012] when the produced item of imperfect production system obeys general distribution pattern, with its quality being perfect, imperfect or defective. The fractions of such items were restricted to constants and they also established that their model becomes classical EPQ model in case imperfect quality percentage is zero or even close to zero. Recently, Wee [2013] used renewal reward theorem to construct economic production quantity model for imperfect items with shortage and screening constraint using time interval as decision variable and shown the robustness of the model. The purpose of this paper is to bring to point that how the recent models over estimates cost in such an environment where one of the major cost of the model largely reduced because of experience of previous production cycle. Thus, present paper concentrates on detailed aspects of imperfect production inventory model, which focuses on practical facet of production in which the manager get advantages of experience and learning to reduce his total production inventory cost. This model generalists the previous models developed by Al-Salmah et al. [2012] and various other models in the literature. This work emphasizes the newer research paradigms and account for accurate cost calculation which will motivate the manager to maximize his profit.

ASSUMPTIONS AND NOTATIONS

To develop an inventory model with variable demand and fractional backlogging the following notations and assumptions are used:

1. Assumptions
2. Demand rate is taken as linear.
3. Deterioration rate is time dependent.
4. Shortages are allowed with fractional backlogging.
5. Backlogging rate is an exponential decreasing function of time.
6. Replenishment rate is infinite.
7. A single item is considered over the prescribed interval.
8. There is no repair or replenishment of deteriorated units.

Notations

$I(t)$ The inventory level at time t.

θt Variable rate of defective units out of on hand inventory at time t, $0 < \theta << 1$.

C' The inventory ordering cost per order.

C_1 are the holding cost per unit per unit time

C_2 unit purchase cost per unit

C_3 shortage cost per unit per unit time

C_4 lost sale cost per unit per unit time

t_1 is the time at which shortage starts and T is the length of replenishment cycle? $0 \le t_1 \le T$.

$f(t) = a + bt$

The variable demand rate is, a > 0, b > 0.

Here a is initial rate of demand, b is the rate with which the demand rate increases.

$\exp(-\delta t)$ Unsatisfied demand is backlogged at a rate; the backlogging parameter δ is a positive constant.

FORMULATION AND SOLUTION OF THE MODEL

The depletion of inventory during the interval (0, t_1) is due to joint effect of demand and deterioration of items and the demand is fractionally backlogged in the interval (t_1, T). The differential equations describing the inventory level I (t) in the interval (0, T) are given by

$$I'(t) + \theta t\ I(t) = -f(t),\ 0 \le t \le t_1 \quad \ldots (1)$$

$$I'(t) = -f(t)\ e^{-\delta t},\ t_1 \le t \le T \quad \ldots (2)$$

with the conditions, I (t_1) = 0 and I (0) = S … (3)

The solutions of equations (1) and (2) can be obtained as

$$I(t) = a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{a\theta}{6}(t_1^3 - 3t_1 t^2 + 2t^3) + \frac{b\theta}{8}(t_1^2 - t^2)^2, 0 \le t \le t_1 \quad \ldots (4)$$

and $$I(t) = \left\{a\delta^2 + b\delta(\delta t + 1)\right\}\frac{e^{-\delta t}}{\delta^3} - \left\{a\delta^2 + b\delta(\delta t_1 + 1)\right\}\frac{e^{-\delta t_1}}{\delta^3},\ t_1 \le t \le T \quad \ldots (5)$$

Also the initial inventory level

$$S = at_1 + \frac{b}{2}t_1^2 + \frac{a\theta}{2}\frac{t_1^3}{3} + \frac{b\theta t_1^4}{8} \quad \ldots (6)$$

The inventory holding cost (C_H) per cycle is given by

$$C_H = C_1 \int_0^{t_1} I(t)dt = C_1\left(\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{a\theta t_1^4}{12} + \frac{b\theta t_1^5}{15}\right) \quad \ldots (7)$$

The deterioration cost (C_D) per cycle is given by

$$C_D = C_2\left\{I(0) - \int_0^{t_1} f(t)dt\right\} = C_2\left\{\frac{a\theta t_1^3}{6} + \frac{b\theta t_1^4}{8}\right\} \quad \ldots (8)$$

The shortage cost (C_S) per cycle due to backlog is given by

$$C_S = -C_3\int_{t_1}^{T} I(t)dt = \frac{C_3}{\delta^4}\left\{a\delta^2 + b\delta(2 + \delta T)\right\}e^{-\delta T}$$

$$-\frac{C_3}{\delta^4}\left[a\delta^2\left\{1 - \delta(T - t_1)\right\} + b\delta\left\{(2 - \delta T)(1 + \delta t_1) + \delta^2 t_1^2\right\}\right]e^{-\delta t_1} \quad \ldots (9)$$

and the opportunity cost (C_0) per cycle due to lost sales is given by

$$C_0 = C_4\int_{t_1}^{T}(1 - e^{-\delta t})(a + bt)dt$$

$$= C_4\left[a(T - t_1) + \frac{b}{2}(T^2 - t_1^2) + \frac{1}{\delta^3}\left\{a\delta^2 + b\delta(1 + \delta T)\right\}e^{-\delta T}\right.$$

$$-\frac{1}{\delta^3}\left\{a\delta^2+b\delta(1+\delta t_1)\right\}\Big]e^{-\delta t_1} \qquad \ldots(10)$$

Hence, the total average cost of the system is given by

$$TC=\frac{1}{T}(C'+C_H+C_D+C_S+C_O) \qquad \ldots(11)$$

$$=\frac{1}{T}[C'+C_1\left(\frac{at_1^2}{2}+\frac{bt_1^3}{3}+\frac{a\theta t_1^4}{12}+\frac{b\theta t_1^5}{15}\right)+C_2\left\{\frac{a\theta t_1^3}{6}+\frac{b\theta t_1^4}{8}\right\}$$

$$+\frac{C_3}{\delta^4}\left\{a\delta^2+b\delta(2+\delta T)\right\}e^{-\delta T}$$

$$-\frac{C_3}{\delta^4}\Big[a\delta^2\left\{1-\delta(T-t_1)\right\}+b\delta\left\{(2-\delta T)(1+\delta t_1)+\delta^2 t_1^2\right\}\Big]e^{-\delta t_1}$$

$$+C_4[a(T-t_1)+\frac{b}{2}(T^2-t_1^2)+\frac{1}{\delta^3}\left\{a\delta^2+b\delta(1+\delta T)\right\}e^{-\delta T}$$

$$-\frac{1}{\delta^3}\left\{a\delta^2+b\delta(1+\delta t_1)+c(2+2\delta t_1+\delta^2 t_1^2)\right\}e^{-\delta t_1}]]$$

To minimize total average cost per unit time, the optimal values of t_1 and T can be obtained by solving the following equations simultaneously

$$\frac{\partial TC}{\partial t_1}=0 \qquad \ldots(12)$$

and $$\frac{\partial TC}{\partial T}=0 \qquad \ldots(13)$$

provided they satisfy the following conditions

$$\left.\begin{array}{l}\dfrac{\partial^2 TC}{\partial t_1^2}>0,\ \dfrac{\partial^2 TC}{\partial T^2}>0 \\ \text{and } \left(\dfrac{\partial^2 TC}{\partial t_1^2}\right)\left(\dfrac{\partial^2 TC}{\partial T^2}\right)-\left(\dfrac{\partial^2 TC}{\partial t_1\partial T}\right)^2>0\end{array}\right\} \qquad \ldots(14)$$

The numerical solution of these equations can be obtained by using some suitable computational numerical method.

NUMERICAL ILLUSTRATION

To illustrate the model numerically the following parameter values are considered.

a = 25 units, C' = Rs.250 per order

b = 12 units,

C_1 = Rs.2.0 per unit per year

c = 5 units,

C_2 = Rs.12.0 per unit

θ = 0.04 units,

C_3 = Rs.15 per unit per year

C_4 = Rs. 3.0 per unit δ = 0.5

then for the minimization of total average cost and with help of software MATLAB 7.0.1 the optimal policy can be obtained such as

t_1 = 0.89456, T = 2.7834, TC= 58.2408

SENSITIVITY ANALYSIS

Table 1: Variation in system parameters

Parameter	%	-50	-25	0	25	50
a	t_1	0.89398	0.89441	0.89456	0.89463	0.89479
	T	2.7281	2.7646	2.7834	2.8067	2.8193
	TC	57.8903	58.1145	58.2408	58.8923	59.0632
B	t_1	0.89362	0.89435	0.89456	0.89489	0.89496
	T	2.7190	2.7578	2.7834	2.8124	2.8347
	TC	55.6719	56.7891	58.2408	59.6720	60.8914
δ	t_1	0.82624	0.84495	0.89456	0.91672	0.93781
	T	2.7365	2.7645	2.7834	2.7964	2.8352
	TC	54.3672	55.7823	58.2408	60.4721	62.2574
θ	t_1	0.93789	0.91681	0.89456	0.85782	0.82163
	T	2.8289	2.7923	2.7834	2.7735	2.7379
	TC	53.6705	55.2289	58.2408	61.7820	63.8203

CONCLUSION

This paper strives; an inventory model for a decaying item with linear demand. We allow the shortages with fractional backlogging in this model and backlogging rate is an exponential decreasing function of time. From the analysis of model, it has been concluded that if the demand parameters are increases then the time and total cost are increases. If the deterioration parameter is increases then the time is decreases and total cost is increases. We use a numerical example to illustrate the model and sensitivity analysis. Also, the effects of changes of different parameters are studied graphically on the average cost.

A natural extension of this research is to consider finite replenishment. Also we extend the deterministic demand function to stochastic demand patterns. Furthermore, we could generalize the model to allow for permissible delay in payments which are more suited to present-day market conditions. Hence, from the economical point of view, the proposed model will be useful to the business houses in the present context as it gives better inventory control system.

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