Inventory Management - A Teaching Note

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Inventory Management - A Teaching Note

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1 Inventory - An Introduction

Inventory (also known as stock) refers to goods or materials that are held by an organization for future usage. Such goods include (i) raw materials, (ii) purchased parts, (iii) components, (iv) sub assemblies, (v) work-in-process, (vi) finished goods and (vii) supplies. One main reason that organisations maintain inventory is that it is rarely possible to forecast / predict sale levels, production times, demand and usage needs exactly. An inventory system is the set of policies and controls that monitors levels of inventory, in order to minimise the inventory cost and to guarantee a smooth operation of the organisation. The purposes of inventory are:

- To maintain independence of operations
- To meet variation in product demand
- To allow flexibility in production scheduling
- To provide a safeguard for variation in raw material delivery time
- To take advantage of economic purchase order size

Inventory serves as a buffer against uncertain and fluctuating demand / usage and keeps a supply of items available until supplies are received. Therefore an inventory system essentially answers two important questions.

1. **How much** should be ordered when the inventory for the item is replenished?

2. **When** should the inventory for a given item be replenished?
It may be understood that all materials involved in an inventory as *an organization’s money in transit* and hence the overall objective of an effective inventory is to minimize the money that is mobilized across all points and to reduce wastages in total. In that perspective, a more recent approach is the JIT. Just-in-time (JIT) is a philosophy of material management and control, with a primary objective of eliminating all sources of waste, including unnecessary inventory. JIT system involves final production or assembly, only when the orders are placed and when demands are exactly known.

### 1.1 Inventory costs

Now, let us identify what are all the costs involved in an inventory system. Broadly there are five categories.

1. **Holding (or carrying) costs**: storage facilities, handling, insurance, pilferage, breakage, obsolescence, depreciation, taxes, and the opportunity cost of capital.

2. **Ordering costs**: typing, calling, transportation, receiving, etc. This cost does not depend on quantity ordered.

3. **Shortage costs (stockout costs)**: the loss due to losing a specific sale, customers goodwill, or future business.

4. **Setup (or production change) costs**: line conversion, equipment change-over, report preparation, etc.

5. **Cost of the item**.

The notation and units of the above costs are as follows.

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1.2 Inventory models

An inventory system can be modelled quantitatively based on demand patterns. They are

- Deterministic inventory models in which demand rate of an item is assumed to be constant.

- Probabilistic inventory models where the demand for an item fluctuates and is specified in probabilistic terms.

Based on the frequency at which orders are placed for procuring inventory, there are two models. They are single period and multi-period inventory systems. There are few sub-categories in multi-period review models. Each of them is briefly discussed below.

- Single Period models: Typically orders are made only once. They are also known as the Dollar Limit System and are used for one time ordering for seasonal products or spare parts purchases.

- Multi Period models: Orders are placed multiple times over the entire production cycle. Based on the pattern of reviewing current inventory, they are further classified.

  Continuous Review (also called Fixed Quantity or Q system): Inventory is reviewed continuously and when inventory drops to a certain (prefixed) reorder level, a fixed quantity is ordered. This model is generally used for high volume, valuable, or important items.

  Periodic Review (also called as P system): Inventory is reviewed at (prefixed) periodic intervals irrespective of the levels to which inventory drops; an order is placed to bring up the inventory to the maximum level. This is used for moderate volume items.

- Other inventory systems: Several other systems use a combination of traditional approaches.

  Optional replenishment system: Inventory is reviewed on a fixed frequency and a specific quantity is ordered, if inventory is below a certain level. This is a mix of the P and Q systems.

  Two-bin system: An inventory amount equal to R is kept in reserve in a second bin. When the first bin is emptied, the second bin is emptied into the first and an order of size Q is placed.

  One-bin system: This is the P-system where one bin is reviewed at a fixed interval and inventory is brought up to a certain level.

  ABC Inventory planning: Inventory items are classified into three groups on the basis of annual dollar volume. Inventory items with a high dollar volume are more frequently
reviewed compared to a low dollar volume.
A: high dollar volume items, say 15% of the total number of items
B: moderate dollar volume items, say the next 35%
C: low dollar volume items, the last 50%

2 Probabilistic Models

In practice, all demand patterns are uncertain and hence a large number of inventory systems cannot be modelled using deterministic approaches. In probabilistic models, demands are described by probability distributions based on which inventory is decided.

2.1 Single-period inventory model with probabilistic demand

It is necessary to clarify the term single period. This term refers to the situation where the inventory is perishable and demand for that particular inventory exists only for the period at which it is ordered (or) procured. Newspaper selling is such an example. The newspaper ordered for today will not be sold at the same price tomorrow. Fashion selling is another example. Spring-summer designs will not sell during the autumn-winter season.

Increment analysis is used to determine the optimal order quantity for a single-period inventory model with probabilistic demand. The increment analysis addresses the how-much-to-order question by comparing the cost or loss of ordering one additional unit with the cost or loss of not ordering one additional unit. Notation used in this model is listed below.

- \( C_o \) : Cost per unit of overestimating demand; represents the loss of ordering one additional unit that may not sell.
- \( C_u \) : Cost per unit of underestimating demand; represents the loss of not ordering one additional unit for which demand existed otherwise.

Let the probability of the demand of inventory being more than a certain level \( y \) is \( P(D > y) \), and the probability of the demand of inventory being less than or equal to this level \( y \) is \( P(D \leq y) \). Then, the expected loss \( (EL) \) is given by either of the two conditions below.

**Overestimation:** \( EL(y + 1) = C_o \times P(D \leq y) \)

**Underestimation:** \( EL(y) = C_u \times P(D > y) \)

Following which the optimal order quantity \( (y^*) \) can be found as follows:

\[
EL(y^* + 1) = EL(y^*)
\]
Hence

\[ C_o \times P(D \leq y^*) = C_u \times P(D > y^*) \tag{2} \]

It is known that

\[ P(D > y^*) = 1 - P(D \leq y^*) \tag{3} \]

Substituting Eqn. 3 into Eqn. 2, we have

\[ C_o \times P(D \leq y^*) = C_u \times [1 - P(D \leq y^*)] \tag{4} \]

Solving for \( P(D \leq y^*) \), we have

\[ P(D \leq y^*) = \frac{C_u}{C_u + C_o} \tag{5} \]

The above expression provides the general condition for the optimal order quantity \( y^* \) in the single-period inventory model. The determination of \( y^* \) depends on the probability distribution.

**Worked out example 1:** (Uniform probability distribution) Emmas Shoe Shop is to order some new design mens’ shoes for the next spring-summer season. The shoes cost Rs.4000 per pair and retail Rs.6000 per pair. If there are still shoes not sold by the end of July, they will be put on clearance sale in August at the price of Rs.3000 per pair. It is expected that all the remaining shoes can be sold during the sale. For the size 10D shoes, it is found that the demand can be described by the uniform probability distribution, shown in Figure 1. The demand range is between 350 and 650 pairs, with average, or expected, demand of 500 pairs of shoes.

![Demand distribution for Size 10D shoes](image)

Figure 1: Demand distribution for Size 10D shoes

Determine the optimal order quantity of size 10D shoes.
**Solution:**
Cost per pair of overestimating demand is equal to the purchase cost minus the sale price per pair; that is

\[ C_o = Rs.4000 - Rs.3000 = Rs.1000 \]

Cost per pair of underestimating demand is the difference between the regular selling price and the and the purchase cost; that is

\[ C_u = Rs.6000 - Rs.4000 = Rs.2000 \]

Substituting \( C_o \) and \( C_u \) into equation 5, we have

\[ P(D <= y^*) = \frac{C_u}{C_u + C_o} = \frac{20}{20 + 10} = \frac{2}{3} \]

Since the probability distribution is uniform, the optimal order quantity \( y^* \) is determined by finding the value of \( y \) that will provide \( P(D <= y^*) = \frac{2}{3} \). ie.,

\[ y^* = 350 + \frac{2}{3}(650 - 350) = 550 \]

The optimal order quantity of size 10D shoes is 550 pairs.

**Exercise:** (Normal probability distribution)Kremer Chemical Company has a contract with one of its customers to supply a unique liquid chemical product. Historically, the customer places order approximately every 6 months. Since the chemical needs 2 months ageing time, Kremer will have to make its production quantity decision before the customer places an order.

- **Detailed information:**
  - Kremer’s manufacturing cost: \( Rs.15/kg \)
  - Fixed selling price: \( Rs.20/kg \)
  - Underestimation (Kremer to buy substitute + transportation): \( Rs.24/kg \)
  - Overestimation (Kremer to reprocess and sell the surplus): \( Rs.5/kg \)

Figure 2 illustrates the demand distribution.

Determine the number of kilograms of the chemical to produce in anticipation of the customer’s order.

Multi-period inventory models with probabilistic demands are not covered in our session.
3 Deterministic Models

The order quantity (how much) and reorder point (when) are determined deterministically by minimising the total inventory cost that can be expressed as a function of these two variables. The total inventory cost ($TC$) is generally composed of the following components:

$$TC = T_c + T_o + T_s + D \times C,$$

where $D$ is the demand, specified as the number of total units needed for the entire planning period. The purchasing cost ($D \times C$) becomes large, when the order size is large. The ordering cost represents the fixed charge incurred when an order is placed. Thus, frequent smaller orders will result in a higher ordering cost than less frequent larger orders. The holding cost, which represents the costs of carrying inventory in stock (e.g., interest on invested capital, storage, handling, depreciation, and maintenance), normally increases with the level of inventory. Shortage of an item leads to two situations; either it shall be a lost business or a back order, when the order is accepted with a promise to deliver at the next time period. Both incur a penalty, the major component being the loss of customer’s goodwill. It is very difficult in any business setup to deduce the monetary equivalent of loss of customer goodwill. What can be approximately quantified is shortage cost.

3.1 Single-item static (EOQ) model with no shortages

This is the best known and most fundamental inventory model, which is applicable when the demand for an item has constant, or nearly constant, rate and when the entire quantity ordered arrives in inventory at on point in time. This condition of instantaneous replenishment is also...
termed as zero lead time (Lead time is the time taken for the inventory to arrive, once ordered; ie., it is the time difference between arrival of orders and instant at which order is placed). The model also assumes no shortages and is illustrated in Figure 3. As observed in Figure 3, when the inventory reduces at an uniform demand rate of $D$ to 0, an order for a quantity $Q$ is placed, which is instantaneously replenished. Let annual demand be $D/year$ and is assumed to be known (as it is a deterministic model).

$$Number\ of\ orders/year = \frac{D}{Q}$$ \hspace{1cm} (7)

$$Total\ order\ cost = \frac{D}{Q} \cdot C_o \ Rs./year$$ \hspace{1cm} (8)

$$Average\ inventory = \frac{Q}{2} \ units$$ \hspace{1cm} (9)

$$Cost\ of\ items = D \cdot C \ Rs./year$$ \hspace{1cm} (10)

Substituting the respective values in Eqn. 6,

$$TC = \frac{D}{Q} \cdot C_o + \frac{Q}{2} \cdot C_c + D \cdot C$$ \hspace{1cm} (11)

where shortage is assumed to be zero. The above expression is linear with only one variable, $Q$ and all others constant. The objective in this modelling is to determine the optimal order

Figure 3: Single-item static (EOQ) model with no shortages
quantity \( Q(= Q^*) \) that minimizes the total cost \( TC \). Differentiating \( TC \) and equating to 0,

\[
\frac{dTC}{dQ} = \frac{-D}{Q^2} \cdot C_o + \frac{C_c}{2} = 0
\]  

(12)

Reducing,

\[
Q = \sqrt{\frac{2D \cdot C_o}{C_c}}
\]  

(13)

Since all are positive constants, \( Q \) in the above expression is also positive. Differentiating Equation 12 once again,

\[
\frac{d^2 TC}{dQ^2} = \frac{2 \cdot D \cdot C_o}{Q^3}
\]  

(14)

Since \( Q \) is positive from Equation 13, \( (d^2 TC/dQ^2) \) shall always be positive in Equation 14. Therefore it is concluded that the value of \( Q \) as deduced in Equation 13 is optimal.

\[
Q^* = \sqrt{\frac{2D \cdot C_o}{C_c}}
\]  

(15)

In practice, an order takes time to be filled. The time lag from the point at which an order is placed until the order is delivered is called the lead time, denoted by \( L \) and is illustrated in Figure 4. Reordering point or replenishment level is given by \( R \) and is given by

\[
R = L \cdot D
\]  

(16)
3.2 Solved example

Let in a manufacturing unit, demand per year for a particular item is 10000 units. The ordering cost is Rs.300/order and unit cost of the item is Rs.4. The carrying or hold cost is given by \( i = 20\% \) of items, which makes the carrying cost as Rs.4/unit/year. Find out the optimal order quantity and the total cost.

\[
Q^* = \sqrt{\frac{2 \times 10000 \times 300}{4}} = 1224.74
\]

Ignoring the constant component of the total cost, which is the cost of units \((D \times C)\).

\[
TC = \frac{D}{Q^*} \times C_o + \frac{Q^*}{2} \times C_c = 4898.98
\]

Figure 5 is a plot that illustrates the distribution of each cost component in a EOQ Model. It is observed that at the optimal order quantity, ordering cost equals holding cost and the total cost is minimum. This can also be verified using the solved example.

Notes

1. Are we justified in designating \( Q \) to be a continuous variable?
   The order quantity can just be rounded off to find the optimal quantity of discrete items.

2. If items are discrete quantities, what should be the optimal order quantity and the corresponding total cost?
   Variations in total cost is insignificant with small variations in order quantity. This can be verified from the solved example above by computing total cost for different values for \( Q \).
   - When \( Q = 1200 \), \( TC = 4900 \)
   - When \( Q = 1300 \), \( TC = 4907.69 \)
   The inference is
     
     If \( Q > Q^* \Rightarrow \) Ordering cost > Carrying cost
     \( Q < Q^* \Rightarrow \) Ordering cost < Carrying cost

   The same can be verified from the plot shown in Figure 5 also.

3. The foremost question in this session is how much to order and when to order. What is the order periodicity for the optimal order quantity?
   Number of orders in a year can be computed as \((N = \frac{D}{Q})\), which is \((= \frac{10000}{1224.74})\)
   8.17. Rounding off, 8 number of orders would make an annual order quantity of 1250 with a total cost of approximately Rs. 4905.
3.3 Single-item static (EOQ) model with shortages

Let us relax the constraints that are specified in the first model, by eliminating the no shortage assumptions. A shortage is a demand that cannot be supplied immediately. The impact of shortage is either a lost business or back-ordering. A back-ordering is a condition where-in orders are continued to be accepted, even when the inventory is zero, so as to supply as and when orders are replenished. Automobile dealers are good examples for this model. This model mainly applies to industries, where holding costs are much higher than shortage costs and lead time is either less or can be reduced easily. To summarise the assumptions:

- Shortage cost is small
- No demand is lost because of shortage as the customers will back order
- Delayed delivery is accepted
- Replenishment is instantaneous

The EOQ inventory model when shortages are allowed is illustrated in Figure 6. Item cost being a constant, let us ignore it, to compute the expression for optimal order quantity and total cost. Average inventory maintained is illustrated as positive inventory \((Q - s)\) over the time period \(t_1\) in Figure 6. Therefore,

\[
\frac{t_1}{t_1 + t_2} = \frac{Q - s}{Q} \tag{17a}
\]

\[
Average\ inventory = \frac{Q - s}{2} \times \frac{t_1}{t_1 + t_2} \tag{17b}
\]
Figure 6: EOQ Model when shortages are allowed

And hence holding cost is

\[ T_c = \frac{(Q - s)^2}{2 * Q} * C_c \]  \hspace{1cm} (17c)

Similarly shortage cost is found for the average shortage of negative quantity during the time period \( t_2 \) and letting the shortage cost per unit item per unit time as \( C_s \).

\[ \frac{t_2}{t_1 + t_2} = \frac{s}{Q} \]  \hspace{1cm} (18a)

\[ \text{Average shortage} = \frac{s}{2} * \frac{t_2}{t_1 + t_2} \]  \hspace{1cm} (18b)

And hence shortage cost is

\[ T_s = \frac{s^2}{2 * Q} * C_s \]  \hspace{1cm} (18c)

Substituting the holding cost (Equation 17c) and the shortage cost (18c) in total cost expression (Equation 6) and ignoring the item cost components,

\[ TC = \frac{D}{Q} * C_o + \frac{(Q - s)^2}{2 * Q} * C_c + \frac{s^2}{2 * Q} * C_s \]  \hspace{1cm} (19)

The above equation is linear and does not have any dependencies. The only variables are the order quantity \( Q \) and the shortage \( s \). Partial differentiating Equation 19 w.r.t shortage \( s \),

\[ \frac{\partial TC}{\partial s} = \frac{C_c}{2 * Q} * [-2 * (Q - s)] + \frac{2 * S}{2 * Q} * C_s \]  \hspace{1cm} (20a)
\[(Q - s) * C_c = s * C_s\]  \hspace{1cm} (20b)

\[Q * C_c = s * (C_s + C_c)\]  \hspace{1cm} (20c)

\[s = \frac{Q * C_c}{C_s + C_c}\]  \hspace{1cm} (20d)

Partial differentiating Equation 19 w.r.t order quantity \(Q\),

\[
\frac{\partial TC}{\partial Q} = -\frac{D}{Q^2} * C_o + \frac{C_c}{2} * \left[\frac{Q * 2 * (Q - s) - (Q - s)^2}{Q^2}\right] - \frac{s^2}{2} * \frac{Q^2 * C_s}{C_s + C_c} \tag{21a}
\]

\[-2D * C_o + C_c * [2Q^2 - 2Qs - Q^2 - s^2 + 2Qs] - s^2 * C_s = 0 \tag{21b} \]

\[-2D * C_o + C_c * (Q^2 - s^2) - s^2 * C_s = 0 \tag{21c} \]

\[-2D * C_o + (C_c * Q^2) - [s^2 * (C_c + C_s)] = 0 \tag{21d} \]

Substituting for \(s\) from Equation 20d

\[-2D * C_o + C_c * Q^2 - \frac{Q^2 * C_c^2}{C_s + C_c} = 0 \tag{21e} \]

\[-2D * C_o + \frac{Q^2 * C_c * (C_c + C_s) - Q^2 * C_c^2}{(C_c + C_s)} = 0 \tag{21f} \]

\[-2D * C_o + \frac{Q^2 * C_s * C_c}{(C_c + C_s)} = 0 \tag{21g} \]

which implies

\[Q^2 * C_c * C_s = 2D * C_o * (C_c + C_s) \tag{21h} \]

\[Q = \sqrt{\frac{2DC_o * (C_c + C_s)}{C_c * C_s}} \tag{21i} \]

Optimal values of order quantity and shortage are given by equations 21i and 20d respectively. Optimality verification by partial differentiating twice the expression for \(TC\) is left as an exercise.
3.4 Solved example

Let us assume shortages are allowed with a cost of Rs. 25/unit/year in the data given in the previous solved example. Substituting in Equations 21i, 20d and 19, the optimal values of order quantity, shortage and total costs can be found, respectively.

\[ Q^* = 1319.09 \]
\[ s^* = 181.94 \]
\[ TC = T_o + T_c + T_s \]
\[ TC^* = 2274.43 + 1960.61 + 313.68 = 4548.72 \]

It is observed by comparing the above solutions with the solutions under no shortage assumption that the order quantity increases and the total cost reduces as additional constraints are imposed on the model.

4 Quantity Discounts in EOQ Model

In the EOQ model, the purchasing cost per unit item is neglected in the analysis because it is constant and hence should not affect the level of inventory. However, it often happens that the purchasing price per unit depends on the size of the quantity purchased. This situation usually occurs in the form of discrete price breaks or quantity discounts. In such cases, the purchasing price should be considered in the inventory model.

4.1 All quantity discount

Consider the inventory model with instantaneous stock replenishment and no shortage. Assume a discount of 2% is offered on order quantities in excess of 2000 units and a 3% discount on orders in excess of 5000 units. Calculating total costs using the data given in solved examples and Equation 6 under three cases:

When \( Q = 2000 \), \( TC = Rs. 201420.00 \)

When \( Q = 1224.74 \), \( TC = Rs. 204898.00 \)

When \( Q = 5000 \), \( TC = Rs. 204300.00 \)

The above values of discount are plotted on a chart\(^1\) in Figure 7. It is inferred that it might

\(^1\)Plot not to scale
be economical to order inventory at the first discount price offered, rather that the computed optimal level (though a case to case evaluation is warranted). This first discount offer (2000 in this example) is called **price break**. Assuming another discount of 0.5% is offered at an order quantity of 1200, which is less than the computed optimal order quantity; then it might be economical to avail that discount of 0.5% at the optimal order quantity of 1224.74. Verification of this statement is left as an exercise.

In summary, if discounts are offered at levels higher than the optimal order quantity, the first discount offer must be chosen and if the discount is at a level lesser than the optimal order quantity, that discount must be availed at the optimal order quantity level. Such discount mechanisms are also known as all quantity discounts, as discount is offered on all items when the quantity exceeds a specified level. An alternate scheme is marginal discount scheme.

### 4.2 Marginal discount

Let a discount of 5% be offered on 2000\(^{th}\) item onwards and items upto 1999 be offered at the original cost price. Letting the carrying cost as \(C_c = i \times C\), where \(i\) is the percentage cost of holding one unit of an item priced at Rs.\(C\), over a unit time. Let \(V_j\) be the monetary value of the first few units with no discount (in this case, 1999) and \(q_j (= 2000)\) be the unit at which
discount applies. Then $TC$ is computed from

$$TC = \frac{D}{Q} \cdot C_o + [V_j + (Q - q_j) \cdot C_i] \cdot \frac{i}{2} + \frac{D}{Q} \cdot [V_j + (Q - q_j) \cdot C_i] \tag{22}$$

From which $Q$ is derived as

$$Q = \sqrt{\frac{2D \cdot (C_o + V_j - q_j \cdot C_j)}{i \cdot C_j}} \tag{23}$$

For the given values, $Q$ is found to be 3479.26 from Equation 23 and total cost is found to be Rs. 203421.28 from Equation 22. Verification of the above expressions and comparative analysis is left as exercise.

## 5 Fixed Time-period Model

In fixed time-period models (also known as P-models), orders are placed at fixed periods, irrespective of the demand or usage pattern. Inventory is not reviewed continuously as in Q-model; but in periodic intervals. An order quantity to replenish available inventory to a maximum level is placed. Because of the uncertain demand pattern, a safety stock is usually maintained; safety stock is the minimum stock levels maintained, which is not accounted for in evaluating the order quantity. Reiterating, order quantity is determined based on demand forecast, and the actual order placed will be over and above the safety stock level. The model is illustrated in Figure 8. The order quantity in this model is dependent on demands, safety stock and current inventory.

$$Q = D \cdot (T + L) + Z \cdot \sigma_{T+L} + I \tag{24}$$

where,

- $D$ is the average demand
- $T$ is the periodicity of review
- $L$ is the lead time
- $Z$ is the number of standard deviations for a specified service probability
- $\sigma_{T+L}$ is the standard deviation of demand over review and lead time
- $I$ is the current inventory (including those being processed in order)

$$\sigma_{T+L} = \sqrt{\sum_{i=1}^{T+L} \sigma^2_{D_i}} \tag{25}$$
Now, $\sigma_{(D_i)}$ can assumed to be constant, as demands are considered independent over any period. Therefore,

$$\sigma_{(T+L)} = \sqrt{(T + L) \cdot \sigma_D^2}$$  \hspace{1cm} (26)

Figure 8: Fixed Time-period Model

6 Summary

In practise, it is very difficult to decide which model should be used in an organization. Generally a combination of different models are used for different items. And a guideline is the ABC approach, discussed earlier.