CHAPTER 2
INVENTORY AND INVENTORY MODELS

Inventory is the stock of any items or resource used in an organization. The objective of inventory management has to keep enough inventories to meet customer demand and also be cost effective. Various costs associated with Inventory are:

a. **Purchase (or production) cost**: The value of an item is its unit purchasing (production) cost. This cost becomes significant when availing the price discounts. This cost is expressed as Rs. /unit.

b. **Capital cost**: The amount invested in an item, (capital cost) is an amount of capital not available for other purchases. If the money were invested somewhere else, a return on the investment is expected. A charge to inventory expenses is made to account for this unreceived return. The amount of the charge reflects the percentage return expected from other investment.

c. **Ordering cost**: It is also known by the name procurement cost or replenishment cost or acquisition cost. Cost of ordering is the amount of money expended to get an item into inventory. This takes into account all the costs incurred from calling the quotation to the point at which the items are taken to stock.

There are two types of costs- Fixed costs and variable costs.

Fixed costs do not depend on the number of orders whereas variable costs change with respect to the number of orders placed. The salaries and wages of permanent employees involved in purchase function and control of inventory, purchasing, incoming inspection, accounting for purchase orders constitute the major part of the fixed costs. The cost of placing an order varies from one organization to another. They are generally classified under the following heads:

(i) **Purchasing**: The clerical and administrative cost associated with the purchasing, the cost of requisitioning material, placing the order, follow-up, receiving and evaluating quotations.

(ii) **Inspection**: The cost of checking material after they are received by the supplier for quantity and quality and maintaining records of the receipts.
(iii) **Accounting:** The cost of checking supply against each order, making payments and maintaining records of purchases.

d. **Transportation costs:** The expenses involved in moving products or assets to a different place, which are often passed on to consumers. For example, a business would generally incur a transportation cost if it needs to bring its products to retailers in order to have them offered for sale to consumers.

Transport costs have significant impacts on the structure of economic activities as well as on international trade. Empirical evidence underlines that raising transport costs by 10% reduces trade volumes by more than 20%. In a competitive environment where transportation is a service that can be bid on, transport costs are influenced by the respective rates of transport companies, the portion of the transport costs charged to users.

e. **Inventory carrying costs (Holding cost):** These are the costs associated with holding a given level of inventory on hand and this cost vary in direct proportion to the amount of holding and period of holding the stock in stores. The holding costs include:

   (i) Storage costs (rent, heating, lighting, etc.)
   (ii) Handling costs: Costs associated with moving the items such as cost of labor, equipment for handling.
   (iii) Depreciation, taxes and insurance.
   (iv) Costs on record keeping.
   (v) Product deterioration and obsolescence.
   (vi) Spoilage, breakage, pilferage and loss due to perishable nature.

f. **Shortage cost:** When there is a demand for the product and the item needed is not in stock, then we incur a shortage cost or cost associated with stock out. The shortage costs include:

   (i) Backorder costs.
   (ii) Loss of future sales.
   (iii) Loss of customer goodwill.
   (iv) Extra cost associated with urgent, small quantity ordering costs.
   (v) Loss of profit contribution by lost sales revenue.
The unsatisfied demand can be satisfied at a later stage (by means of back orders) or unfulfilled demand is lost completely (no back ordering, the shortage costs become proportional to only the shortage quantity).

2.1 Inventory Control—Terminology:

a. **Demand**: it is the number of items (products) required per unit of time. The demand may be either deterministic or probabilistic in nature.

b. **Order cycle**: The time period between two successive orders is called order cycle.

c. **Lead time**: The length of time between placing an order and receipt of items is called lead time.

d. **Safety stock**: It is also called buffer stock or minimum stock. It is the stock or inventory needed to account for delays in materials supply and to account for sudden increase in demand due to rush orders.

e. **Inventory turnover**: If the company maintains inventories equal to 3 months consumption. It means that inventory turnover is 4 times a year, i.e. the entire inventory is used up and replaced 4 times a year.

f. **Re-order level (ROL)**: It is the point at which the replenishment action is initiated. When the stock level reached R.O.L., the order is placed for the item.

g. **Re-order quantity**: This is the quantity of material (items) to be ordered at the re-order level. Normally this quantity equals the economic order quantity.

2.2 Inventory Cost Relationships

There are two major costs associated with inventory. Procurement cost (ordering cost) and inventory carrying cost. Annual procurement cost varies with the number of orders. This implies that the procurement cost will be high, if the item is procured frequently in small lots. The procurement cost is expressed as Rs. /Order.

The annual inventory carrying cost (Product of average inventory X Carrying cost) is directly proportional to the quantity in stock. The inventory carrying cost decreases, if the quantity to be ordered per order is small. The two costs are diametrically opposite to each other. The right quantity to be ordered is one that strikes a balance between the two
opposing costs. This quantity is referred to as “Economic order quantity” (EOQ). The cost relationships are shown in the Fig. 2.1

![Inventory carrying cost](image)

**Fig. 2.1 Inventory carrying cost**

### 2.3 Inventory Models:

One basic problem of inventory management is to find out the order quantity so that it is most economical from an overall operational point of view. Here that problem lies in minimizing the two conflicting costs, i.e., ordering cost and inventory carrying cost. Inventory models help to find out the order quantity which minimizes the total costs (sum of ordering costs and inventory carrying costs). Inventory models are classified as shown in Fig. 2.2
2.4 **Model I**: Economic Order Quantity with Instantaneous Stock Replenishment (Basic Inventory Model)

**Assumptions**

(i) Demand is deterministic, constant and it is known.

(ii) Stock replenishment is instantaneous (lead time is zero)

(iii) Price of the materials is fixed (quantity discounts are not allowed)

(iv) Ordering cost does not vary with order quantity.

Graphical representation of the model is shown in Fig. 2.3
Let $D$ be the annual demand (units per year)

- $C_0 =$ Ordering costs (Rs. /order)
- $C_h =$ Inventory carrying costs (Rs./unit/unit time)
- $C_p =$ Price per unit
- $Q =$ Order quantity
- $Q^* =$ Economic order quantity
- $N =$ Number of orders placed per annum
- $T_c =$ Total cost per annum

$$Q^* = \sqrt{\frac{2DC_0}{C_h}}$$

$$T_{cm} = \sqrt{2DC_0 \cdot C_h}$$

**2.5 Model II:** Economic Order Quantity when stock replenishment is non-instantaneous (Production Model)

This model is applicable when inventory continuously builds up over a period of time after placing an order or when the units are manufactured and used (or sold) at a constant rate.
Because this model is especially suitable for the manufacturing environment where there is a simultaneous production and consumption, it is called “Production Model”.

![Production inventory model](image)

**Fig. 2.4 Production inventory model**

**Assumptions**

(i) The item is sold or consumed at the constant demand rate which is known.

(ii) Set up cost is fixed and it does not change with lot size.

(iii) The increase in inventory is not instantaneous but it is gradual.

Production inventory is represented in the Fig. 2.4

Let \( p \) be the production rate.

\( d \) is the demand or consumption rate.

Replenishment of inventory under this system build-up during the period \( tp \) and consumption takes place during the entire cycle \( T \).

\[
Q^* = \sqrt{\frac{2DC_0}{(1-d/p)C_h}})
\]

\[
N^* = \frac{Annual\ demand}{Economic\ Batch\ Qty\ (EBQ)} = \frac{D}{Q^*}
\]
2.6 Model III: An Inventory Model when shortages are permitted

In many practical situations, shortages or stock outs are not permitted. So, it is must that stocks out situations are to be avoided. There are occasions where stock out are economically justifiable.

This situation is observed normally when cost per unit is very high.

![Inventory model with shortages permitted.](image)

- $C_s$ = Shortage Cost (Stock out cost) per unit per period.
- $S$ = Balance units after back orders are satisfied.
- $Q - S$ = Number of shortages per order.
- $t_1$ = Time period during which inventory is positive.
- $t_2$ = Time during which shortage exists.
- $T$ = Time between the receipt of orders.

The basic assumption is that there is no loss of sales due to stock out or shortages.

$$Q^* = \sqrt{\frac{2DC_0 \cdot \frac{C_S}{C_H}}{C_H \cdot C_S}}$$

$$T_{cm} = \sqrt{\frac{2DC_0 \cdot C_H \cdot \frac{C_S}{C_H + C_S}}{C_S}}$$
2.7 Model IV: Inventory Model with price discounts

When items are bought in large quantities, the supplier often gives discounts. However, if the material is purchased to take advantage of discount, the average inventory level and so the inventory carrying costs will increase.

Benefits for the purchaser from large orders are, lower cost per unit, lower shipping and transportation cost, reduced handling cost and reduction in ordering costs due to less number of orders.

These benefits are to be compared with the increase in carrying costs. As the order size increases, more space should be provided to stock the items.

A decision is, therefore, to be taken whether the buyer should stick to economic order quantity or increase the same to take advantage that, at large quantities, the production costs per piece are lower (economics of scale) and, hence, part of the savings can be passed on to the customer.

Safety Stock

The economic order quantity formula is developed based on the assumption that the demand is known and certain and that the lead time is constant and does not vary. In actual practical situations, there is an uncertainty with respect to both demand as well as lead time. The total forecasted demand may be more or less than actual demand and the lead time may vary from the estimated time. In order to minimize the effect of this uncertainty due to demand and lead time, a firm maintains safety stock, reserve stock or buffer stock.

The safety stock is defined as “the additional stock of material to be maintained in order to meet the unanticipated increase in demand arising out of uncontrollable factors.”

Because it is difficult to predict the exact amount of safety stock to be maintained, by using statistical methods and simulation, it is possible to determine the level of safety stock to be maintained.

a. FSN analysis: All the items in the inventory are not required at the same frequency. Some are required regularly, some occasionally and some very rarely. FSN analysis classifies items into fast moving, slow moving and non-moving.

b. SOS analysis: this classification is based on the seasonality of the items as seasonal and off seasonal. Seasonal items are available only for a limited period and, hence, they are procured to meet the demand till the next season.
c. XYZ analysis: This analysis is based on the value of the stocks on hand (i.e., capital employed to procure inventory). Items whose inventory values are high are called X category and whose values are low are called Z items. Usually XYZ analysis is used in association with A.B.C. analysis.

2.8 Just in Time Philosophy

The roots of the JIT system can probably be traced to the Japanese environment. Japan has inherent limitations of lack of space and lack of natural resources. Japanese have developed an aversion towards all kinds of wastes. They view scrap and rework as waste and hence strive for perfect quality. They strongly believe that inventory storage wastes space and results in locking up of valuable materials and capital. Anything that does not contribute value to the product is viewed as waste. Thus, it is quite natural for the JIT philosophy to develop in Japan. Apart from eliminating wastes JIT has another important feature utilizing the full capability of the worker. Workers in JIT system are charged with responsibility for producing quality parts just in time to support the next production process. The objective of JIT system is to improve profits and return on investment through cost reductions, inventory reduction and quality improvement. Involvement of workers and elimination of waste are the means of achieving these objectives. So, JIT manufacturing is a broad philosophy of continuous improvement that includes three mutually supportive components such as,

a. The People Participation and Involvement:

The stock less production or zero inventories have created an impression that JIT is only an inventory program. JIT has a strong human resource management component that must be recognized in order to exploit the full potential of technology component. The success of JIT depends upon how the companies train their human resource to have an appropriate skill, responsibility and co-ordinate and motivate people JIT seeks to fully utilize the creative talents of employees, suppliers, subcontractors and others who may contribute to the company’s improvement. Teamwork, discipline and supplier involvement are the important components that contribute to the success of JIT.
b. Total Quality Control (TQC):
Total Quality Control refers to the achievement and improvement in quality in a JIT company, which involves every department and each employee in the company, can remain competitive.

c. Internal customer Concept- JIT companies believe in broad definition of a customer. The traditional organization define that customer is a person outside the company who buys and uses the products and services. JIT companies adds to this definition the concept of immediate customer (or internal customer) who is the next person or department or process who uses or further processes them. If each worker sends only defect free items to his immediate customer. No defective final products will be produced.

d. Quality at Source- Each employee is given the responsibility for quality at his work-station. Employees are trained in quality principles and testing procedures. They inspect their own work to ensure that the defectives are not passed onto the next process. The defective element is more easily detected by the immediate customer than by the person who is responsible for it. e.g., a part may not fit in to the assembly if it is not properly made. A procedure called “JIDOKA” is brought in to effect. Any employee who senses that a process is producing defects or is about to go out of proper specification has the authority and the responsibility to stop the process. The concept behind this is that it is better to stop the production rather than producing defects.

e. TQC is a culture not a program: The TQC philosophy aims at the culture of continuous improvement in which people always strive to do better. Companies continue to look for incremental product improvements and process refinements. The objective here is to reduce variability in processes and in parts because it is the variation, which makes the product deviation from quality. Total quality efforts extend to suppliers. When suppliers’ quality reaches a consistently high quality, there is no need for the supplier to go through incoming inspection.

f. JIT Flow: A queue in front of the work center represents the work in process (WIP). Any form of inventory is a waste as per the JIT philosophy when the queues are long, the cost of holding the WIP becomes high and the required for a job to flow through the required work centers becomes excessive. The major objective of JIT is to have only the right item at the right place at the right time. This practice reduces the WIP and hence the working capital requirement but
also the floor space and the flow through time. Thus the important aspects that support the JIT flow are:

a. Uniform production rate and mixed model assembly.
b. Pull method of co-coordinating work centers.
c. Quick and inexpensive set ups.
d. Multi skilled work force and flexible facilities.
e. High quality levels with no rejects or reworks.

2.9 Basic Elements of JIT:

a. Flow layout: The physical layout of production facilities is arranged, so that the process flow is streamlined, i.e., for each component, the proportion of value-added time should be more; there should be minimum queuing and non-value-added times. Use of dedicated lines, U-shaped or parallel lines, use of small machines is preferred. Flexibility of equipment is essential to adjust quickly to changing market demand.
b. Smoothed build up rate: The buildup rate should be smooth over a monthly cycle. To achieve this, under capacity scheduling is resorted to so that they can respond to demand changes.
c. Mixed model scheduling: JIT objective is to match the production rate to demand as closely as possible. One way of doing this is to increase the flexibility of production lines to allow concurrent assembly of different models on the same line.
d. Small lots and minimum set-up time: The objective of minimizing set-up times is to reduce the batch sizes to the minimum possible. This reduces the manufacturing cycle time and inventory. Use of SMED technique (single minute exchange of dies) is recommended.
e. Buffer stock removal: Constant elimination of buffer stocks is emphasized to highlight production problems scheduled by high inventory levels.
f. Kanban card: It is a pull system of managing material movement comprising of “Kanban card” based on information system. It helps to trigger the movements of material from one operation to another (next). Merely by alternating the frequency of the circulating Kanban, the production system can be made to adjust to demand fluctuations within
limits. The number of cards in the system determines the total inventory. Hence, the objective is to minimize the number of kanbans.

g. Quality: The achievement of high quality levels is a prerequisite of successful JIT. Zero defect, statistical process control, process data collection and worker centered quality are commonly used quality programmes.

h. Product and process simplification: This is achieved through
   (i) Rationalization of product range
   (ii) Simplification of methods of manufacture
   (iii) Simplification through component item standardization.

i. Standard container: JIT emphasize small standardized containers. This simplifies materials movement and use of material handling equipment.

j. Preventive maintenance: JIT requires removal of causes of uncertainty and waste. Breakdown is a major cause of the uncertainty. Rigorous preventive maintenance attempts to remove the uncertainty.

k. Flexible workforce: This is the critical requirement of JIT. Flexible workforce is developed through cross functional training. It is necessary to match production rate and demand rate as closely as possible.

l. Organization in modules or cells: Many JIT factories are organized in small autonomous modules or cells, each cell being totally responsible for its own production and supply of adjacent module. The cells are designed so that material flow between the cells is minimized.

m. Continuous improvement: JIT is not one time effort. Kit is a philosophy of continuous improvement. It seeks the involvement of everyone in the continuous improvement.

n. JIT purchasing: Materials and components are purchased in accordance with well defined requirements in terms of quality, quantity and delivery. JIT purchasing vendor development, long-term buyer-seller relationship, vendor involvement in design of products high quality if purchased material, frequent part delivery, etc. supplier JIT is a prerequisite in JIT manufacture. The key elements are represented in a Table.

   Key Elements of JIT
   (i) Have a flexible workforce capable of using multiple skills.
   (ii) Strive for reduced set-up times and small lot sizes.
(iii) Work for a constant master schedule.
(iv) Insist for defect free materials and supplies be delivered when needed.
(v) Use a Kanban or comparable system to pull needed inventory through the system.
(vi) Necessary support system to be developed (Reliable vendors, employee involvement and cooperation, total productive maintenance).

2.10 Benefits of JIT

The most significant benefit of JIT is to improve the responsiveness of the form to the changes in the marketplace thus providing an advantage in competition. The benefits are:

a. Product Cost: It is greatly reduced due to reduction of manufacturing cycle time, reduction of waste, inventories and elimination of non-value-added operations.
b. Quality: It is improved because of continuous quality improvement programmes.
c. Design: Due to fast response to engineering change, alternative designs can be quickly brought on the shop floor.
d. Productivity improvement.
e. Higher production system flexibility.
f. Administrative ease and simplicity.

2.11 Implementation of JIT

To facilitate the implementation of JIT, after JIT the following approach is suggested by Hall.

a. Obtain commitment from top management.
b. Prepare an implementation plan.
c. Gain the co-operation of the work force.
d. Create a strong leadership on the shop floor.
e. Guarantee stable employment, engage training and encourage participation and teamwork.
f. Level the production and smoothen the flow.
g. Reduce set up times of machines/equipments.
h. Balance fabrication rates with final assembly rates.
i. Provide spare capacities in all areas.
j. Extend JIT to suppliers.
k. Remove the bottlenecks and stabilize delivery schedules.
2.12 KANBAN SYSTEM

Kanban system is a simple information system used by a work center to signal its supplier work center to request a replacement container and to authorize production of another container of that particular item. The name comes from a Japanese work “Kanban” which means card or sign. Originally a card was used to signal the supplying work center. A work center can use a variety e.g. a flashing light, the empty container or a computer communication or a message. The purpose of the Kanban system is to signal the need for more parts and to ensure that those parts are produced in time to support subsequent fabrication or assembly. This is achieved by pulling parts through the assembly line. Only final assembly line receives a schedule from the dispatch office. All other operators and suppliers receive production orders (Kanban cards) from the subsequent (using) work centers.

The Kanban system is a physical control system consisting of cards and containers. In the two cards Kanban system, two types of cards are used. The production card (P-card) authorizes the work centers to make on standard container of a particular part specified on the card. The second type of one container of the specified part from a particular work center to another work center as specified on the card. Since these cards are continually reused, they are issued only when the production of an item is to be started or changed significantly.

Assume that the containers are moved one at a time. When the containers of the parts is emptied at worker center B, the empty container and the withdrawal card are taken back to work center A. The production card from a full container of parts is removed from its container and replaced by the withdrawal card. The production card is then placed in the Kanban receiving post at work center A, there by authorizing production of another container of parts. The empty container is left at work center A. The full container and its withdrawal card are moved to work center B and placed in the input area. When this container or parts is used, its withdrawal card is empty container are taken back to work and the cycle is repeated.

The number of containers needed to operate a work center is a function of the demand rate container rate and the circulating time for a container. The number of containers can be found mathematically.

2.13 Comparison between JIT and MRP

In comparing the relationship between JIT and MRP, it is important to understand the distinction between push and pull system of production control. A push system like MRP pushes material
into production to meet future needs. Master schedule is based on future forecasts/orders which determine what components are to be ordered and pushed through production. In pull system, such as JIT, material is pulled through production by subsequent work centers. Materials are only provided only when there is a subsequent demand; there is no pushing of materials in to production to meet future demands.

MRP can be used for a dynamic situation i.e. when the demand could change significantly in future; JIT is incapable of taking large and sudden variations. JIT is a single unit production where as MRP involve lot sizes at all levels of the product. JIT eliminates inventories where as MRP is able to make some compromises and even keep safety stocks to insure against demand and supply variations.

MRP does not require human orientation as a pre requisite as in JIT. In MRP there is not much stress on vendor relations as it is as important element of JIT. Planning in JIT is easy one needs to plan only the smoothened production of the finished products, whereas, in MRP one needs to plan for every intermediate product and process as well.

JIT is preferred in case of repetitive (mass) production where as MRP is suited for job or batch production.