MODULE I Introduction to Production & Operations Management (07 Hours)

Nature, scope and objectives of POM. Evolution of production systems (craft, mass, lean production). Interface with marketing, finance, HR, R&D, and supply chain. Characteristics of manufacturing vs service operations. Role of operations manager; decision types in operations. Trends: Industry 4.0, sustainability, AI in operations. Basics of Operations Research and its application in decision-making.

Introduction

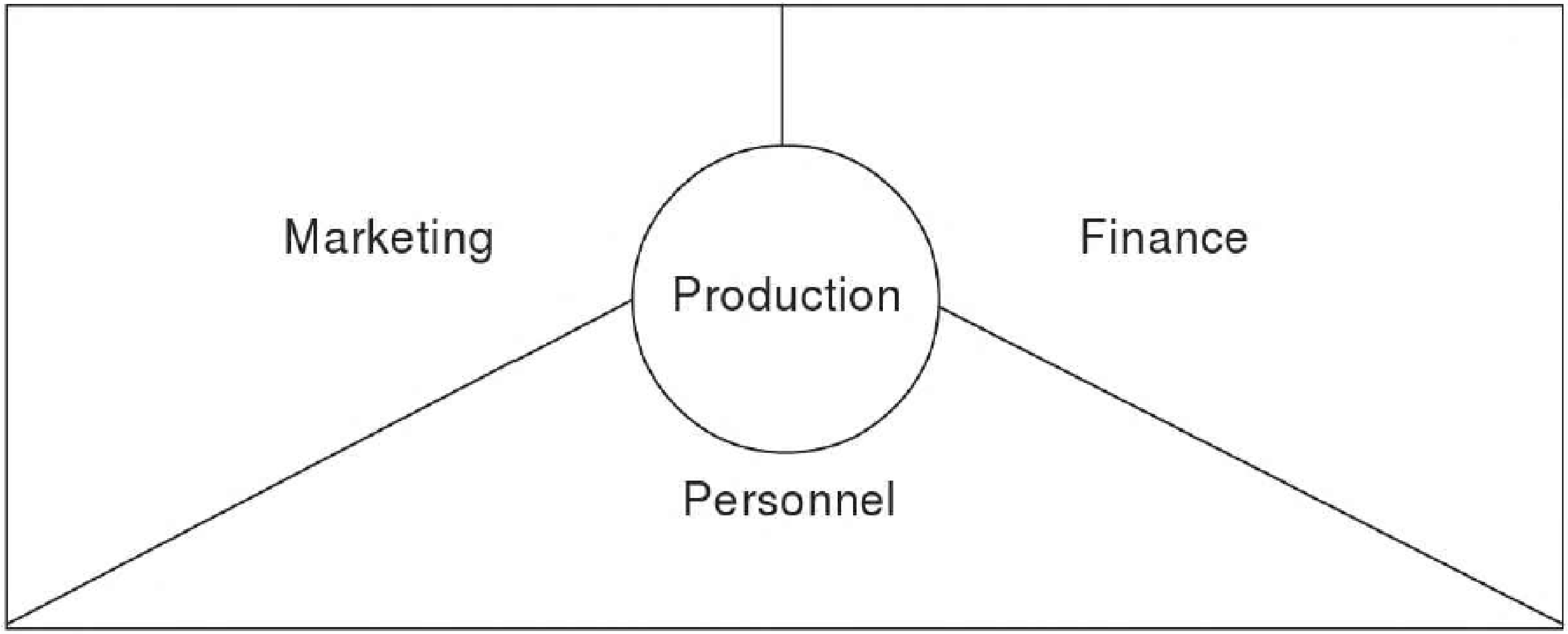
Among different functions in any organization, production and operation function is a vital function which does the job of value addition to products / services respectively.

Maximizing the value addition automatically results in productivity improvement.

An organization consists mainly of four functional subsystems,

- ✓Marketing,
- ✓Production,
- ✓Finance and
- ✓Human resource management

A **functional subsystem** of an organization refers to a specific area or department that **performs a distinct function contributing** to the **overall goals of the organization**. Each subsystem focuses on a particular set of tasks and works in coordination with other subsystems.



Functional System of Organization

(a) Marketing function of an organization aims to

- Develops strategies to promote the organization’s products/services.

- Handles market research, advertising, branding, and customer relationships.

(b) Production/Operations Subsystem

- Responsible for producing goods or delivering services.
- Functions: scheduling, quality control, maintenance, inventory management.

(To manufacture the product as per the specifications, the **production function** needs to organize its resources (raw material, equipments labour and working capacity) according to predetermined production plans.)

(c) Finance and Accounting Subsystem

- Manages the organization's financial resources.
- Functions: budgeting, financial planning, accounting, investment decisions

(The finance function provides authorization and to control to all other subsystems to utilize money more effectively through a well-defined finance plan.)

(d) Human Resource (HR) Subsystem

- Manages employee-related activities.
- Functions: recruitment, training, performance evaluation, compensation, labour relations. (The human resource management function plans and provides manpower to all other subsystems of the organization by proper recruitment and

training programs. It also monitors the performance of the employees by proper motivation for targeted results.)

All the subsystems of an organization are mutually interlinked. They cannot work in isolation. A complete integration of all the functions /subsystems of an organization are absolutely essential for the effective functioning and achievement of desired results.

The concern of any organization today is the pursuit of creating more value for the customer. This value end focus provides the competitive advantage that has become of necessity today.

✓Production and operation management provides the means to explore and implement initiatives on

How to avoid waste,

How to create value? and

How the organization can differentiate itself from its competitors?

✓This differentiation has become the means to survive in this brutal world of competition. In fact, “Operations” greatly influences, directly or indirectly, the value creation logic of the organization.

✓Production and operation management is the science-combination of techniques and systems – that guarantee production of goods and services of the right quality, in the right quantities and at right time with the minimum cost within shortest possible time.

- ✓ The essential features of a production and operation function is to bring together people, machines and materials to provide goods and services for satisfying customer needs.

Production and Operation Management is not independent of marketing, financial, and personnel management due to which it is difficult to formulate some single appropriate definition of Production and Operation Management.

The following definitions try to explain main characteristics of Production and Operation Management:

In the words of Mr. E.L. Brech: “Production and Operation Management is the process of effective planning and regulating the operations of that section of an enterprise which is responsible for the actual transformation of materials into finished products”. This definition limits the scope of operation and production management to those activities of an enterprise which is associated with the transformation process of inputs into outputs. The definition does not include the human factors involved in production process. It lays stress on materialistic features only.

- Production and Operation Management deals with decision making related to production processes, so that the resulting goods and services are produced in accordance with the quantitative specifications and demand schedule with minimum cost. According to this definition design and control of the production system are two main functions of production and operation management.

- Production and Operation Management is a set of general principles for production economies, facility design, job design, schedule design, quality control, inventory control work study and cost band budgeting control. This definition explains the main areas of an enterprise where the principles of production and operation management can be applied. This definition clearly points out that the production and operation management is not a set of techniques,

Production and Operations Management (POM) refers to the administration of processes that transform inputs (such as raw materials, labour, and technology) into finished goods or services efficiently and effectively.

It focuses on:

- **Production Management** – planning, organizing, and controlling the production of goods.

- **Operations Management** – managing the overall processes, including both manufacturing and service operations, to ensure optimal resource utilization, quality, and customer satisfaction.

Difference between Production Management and Operation Management

Production management focuses specifically on manufacturing processes and the production of goods, whereas **operations management extends to service operations and the entire operational system.**

Concept of Manufacturing Products/Providing Services is called as Production/Operation Management.

Production management deals more with the technical aspects of production processes and resource utilization, while operations management deals with both strategic and tactical aspects of operations across the organization.

In essence, **production management can be seen as a subset of operations management**, focusing specifically on the production processes within manufacturing contexts, whereas operations management encompasses a wider range of activities across manufacturing and service sectors.

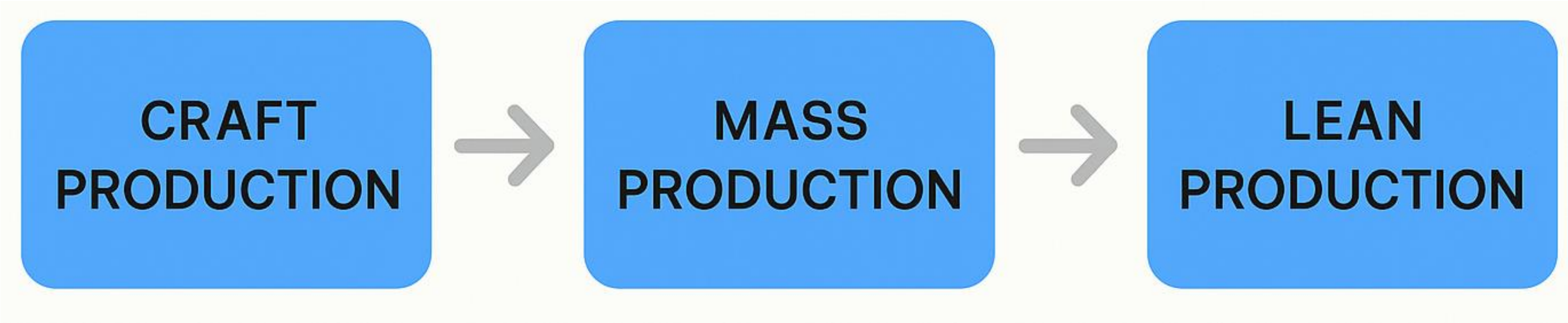
	Production Management	Operation Management
Focus	Managing the production or manufacturing processes within an organization.	Encompasses a broader spectrum of activities beyond just production, including service operations.
Scope	Includes planning, organizing,	Covers all activities involved in

	directing, and controlling all activities involved in the production of goods.	designing, managing, and improving the entire operations process that creates goods and/or services.
Key Responsibilities	Involves managing resources such as materials, machines, and manpower to ensure efficient production.	Includes strategic planning, forecasting, capacity planning, quality assurance, inventory management, logistics, and supply chain management.
Goals	Emphasizes on maximizing productivity, minimizing costs, and ensuring timely delivery of products.	Aims at optimizing the overall operations to achieve efficiency, effectiveness, and customer satisfaction

	Manufacturing customer-made products like boilers with specific capacity, constructing flats, structural fabrication, manufacturing standardized products like car, bus, motor cycle, radio, television etc	Customer-made services like developing standard computer softwares, providing standard insurance policies, i.e. produces intangible items, Quality of output is highly variable. Production and consumption occur simultaneously. No inventory is accumulated

EVOLUTION OF PRODUCTION SYSTEMS

The **evolution of production systems** can be broadly classified into three major stages:



1. Craft Production (Pre-Industrial Era)

- **Time Period:** Before the 18th century.
- **Characteristics:**
    - Products made by skilled craftsmen.
    - Low production volume.

    - Customized goods with high quality.
    - Manual tools, no machines.
    - High cost per unit.
- **Example:** Handmade furniture, tailoring, blacksmithing.

2. Mass Production (Industrial Revolution Era)

- **Time Period:** Late 18th century to mid-20th century.
- **Characteristics:**
    - Standardized products.
    - High-volume production using assembly lines.
    - Use of machines and division of labour.
    - Lower cost per unit due to economies of scale.
    - Less flexibility; products lacked customization.

- **Example:** Ford’s moving assembly line for Model T cars

3. Lean Production (Modern Era)

- **Time Period:** Late 20th century to present.
- **Characteristics:**
  - Focus on efficiency and waste reduction (from Toyota Production System).
  - Just-in-Time (JIT) inventory management.
  - High quality with lower costs.
  - Flexible systems to produce customized products quickly.
  - Employee involvement and continuous improvement (Kaizen).
- **Example:** Toyota, Honda production systems.

Tabular comparison of Craft Production, Mass Production, and Lean Production:

Aspect	Craft Production	Mass Production	Lean Production
Time Period	Pre-18th century	18th–20th century	Late 20th century–present
Volume	Very low	High	Moderate to high
Product Type	Customized	Standardized	Mix of standard & customized
Technology	Manual tools	Machines & assembly lines	Advanced automation & flexible tech
Labour Skill	Highly skilled	Semi-skilled	Multi-skilled
Cost per Unit	Very high	Low	Low to moderate
Flexibility	Very high	Very low	High
Quality	Very high (artisanal)	Consistent but not personalized	High & consistent
Inventory	Made-to-order	Large stock	Just-in-Time (minimal inventory)
Waste	High material use	High waste	Minimal waste

Interface with marketing, finance, HR, R&D, and supply chain.

Detailed explanation of how Production and Operations Management (POM) interfaces with other key functions:

1. **POM and Marketing**

- **Demand Forecasting & Production Planning:** Marketing analyzes customer demand trends; POM uses this data to plan production quantities and schedules.
- **Product Specifications:** Marketing conveys customer requirements (design, quality, packaging), which POM integrates into manufacturing processes.
- **Pricing & Cost Structure:** POM provides production cost data to marketing, influencing pricing strategies.
- **Delivery Commitments:** Marketing sets delivery dates for customers, and POM ensures production aligns to meet those timelines.

2. POM and Finance

- **Budgeting & Resource Allocation:** Finance determines available funds for production, machinery, labour, and inventory.
- **Cost Control:** POM works with finance to reduce operational costs (labour, materials, energy) while maintaining quality.
- **Investment Decisions:** For expansion or automation, POM provides technical data, and finance evaluates the financial feasibility.
- **Working Capital Management:** Finance ensures adequate liquidity to maintain inventory, pay suppliers, and manage operational expenses

3. POM and Human Resources (HR)

- **Manpower Planning:** HR ensures the right number of skilled employees are available for production shifts.
- **Training & Skill Development:** POM communicates required competencies; HR organizes training programs to enhance workforce capabilities.
- **Employee Relations & Safety:** HR establishes policies for labour relations, health, and safety, which affect operational continuity.
- **Performance Evaluation:** HR supports POM in setting productivity targets and evaluating employee performance.

4. POM and Research & Development (R&D)

- **Product Development:** R&D designs prototypes, and POM determines how to produce them efficiently at scale.

- **Process Innovation:** R&D suggests new technologies or processes; POM tests and implements them for efficiency.
- **Quality Standards:** R&D sets performance and quality benchmarks; POM enforces them on the shop floor.
- **Sustainability & New Materials:** R&D develops eco-friendly materials or methods, which POM integrates into production.

5. POM and Supply Chain / Procurement

- **Material Planning:** POM forecasts raw material requirements; procurement ensures timely sourcing.
- **Vendor Management:** POM specifies quality standards; supply chain teams select and manage suitable suppliers.

- **Logistics Coordination:** POM relies on the supply chain to move raw materials in and finished goods out efficiently.
- **Inventory Management:** Supply chain teams help POM maintain optimal inventory levels to avoid both shortages and excess.

Pictorial representation of Interface with marketing, finance, HR, R&D, and supply chain

CHARACTERISTICS OF MANUFACTURING VERSUS SERVICE OPERATIONS, SYSTEM VIEW OF OPERATIONS

Manufacturing vs Production → Tangible product- goods/ nontangible intangible- services

Product	**Services**
1-tangible, durable products.	1- Intangible, perishable products.
2- Output can be inventoried.	2- Output can’t be inventoried.
3-consumption/use takes more time.	3-Immidiate consumption.
4-low costumer’s involvement.	4- High costumer’s involvement.
5-long response time.	5- Short response time.
6-Available at regional, national and international market.	6-local market.
7-Reqire large facilities.	7- Require small facilities.
8-Capital intensive.	8-Labour intensive.
9-Quality easily measured.	9- Quality not easily measured.
10-Demand variable on weekly, monthly, seasonally.	10- Demand variable on hourly, daily, weekly basis.

ROLE OF OPERATIONS MANAGER; DESIGN TYPES IN OPERATIONS

The role of an operations manager is crucial in ensuring efficient production and delivery of goods and services within an organization. They typically oversee the entire production process, from planning and scheduling to manufacturing and quality control. Here are some key responsibilities:

1. **Planning and Strategy:** Operations managers develop operational strategies aligned with the organization's goals, considering factors like resources, market demand, and technological advancements.
2. **Resource Management:** They manage resources such as manpower, materials, and equipment to optimize production efficiency and minimize costs.

3. **Quality Control:** Ensuring that products meet quality standards through continuous monitoring and improvement processes is a critical part of their role.
4. **Process Improvement:** They identify inefficiencies and implement process improvements to enhance productivity and reduce waste.
5. **Supply Chain Management:** Operations managers coordinate with suppliers and distributors to ensure timely delivery of materials and products, optimizing the supply chain.
6. **Risk Management:** They assess and mitigate operational risks to maintain continuity and minimize disruptions in production.
7. **Team Leadership:** Managing and motivating teams to achieve operational goals, ensuring clear communication and fostering a collaborative work environment.

To manage various subsystem of the organization, executives at different levels of the organization need to take several management decisions. Decisions are typically categorized into three main types, based on their level of impact and time horizon:

Management decisions are classified as

(1) Strategic decisions

(2) Tactical decisions

(3) Operational decisions

1. Top-Level Management

Examples: CEO, Managing Director, Board of Directors

- **Type of Decisions:** Strategic
- **Scope:** Long-term, organization-wide
- **Frequency: Low**

- **Reason:** Strategic decisions are complex, long-term, and made less frequently (e.g., mergers, entering new markets).

2. Middle-Level Management

Examples: Department Heads, Division Managers

- **Type of Decisions:** Tactical
- **Scope:** Medium-term, department-specific
- **Frequency: Moderate**
- **Reason:** Middle managers translate strategic goals into departmental plans; decisions are more frequent than top level, but less routine than operational level.

3. Lower-Level (Operational) Management

Examples: Supervisors, Foremen, Line Managers

- **Type of Decisions:** Operational
- **Scope:** Day-to-day tasks, team or unit-specific
- **Frequency: High**

- **Reason:** They handle routine, repetitive decisions related to daily operations like assigning tasks, handling breakdowns, etc.

Relative Frequencies of decisions at different level of management

Level of Management	**Type of Decision**	**Scope**	**Frequency of Decision**
Top-Level	Strategic	Organization-wide	**Low**
Middle-Level	Tactical	Department/Unit	**Moderate**
Lower-Level	Operational	Daily operations	**High**

Matrix of functional subsystems and management activities is shown in Table below (different examples under each combination). Information requirements at the operational level will be largely internal, well defined, narrow and detailed. On the contrary, information requirements at the strategic level will be external, very wide and aggregate in nature. The information requirements at the tactical level will be in between these two extremes.

Management Activity Level	Functional Subsystems			
	Marketing	Production/Operations	Finance	Personnel
Strategic	Consideration of new markets and new marketing strategies. The information requirements for strategic planning include customer analysis, competitor analysis, consumer survey, income projection, demographic projections and technology projections.	Alternative manufacturing approaches and alternative approaches to automation.	Long-run strategy to ensure adequate financing, a long-run tax accounting policy to minimize the impact of taxes, and planning of systems for budgeting.	Strategies for recruitment, salary, training, and benefits. Analysis of shift pattern of employment, education and wage rate etc.
Tactical	Comparison of overall performance against a marketing plan. It concerns data on customers, competitors, competitors' products and sales force requirements.	Summary reports which compare overall planned or standard performance for such classifications as cost per unit and labour used.	Information on budgeted versus actual cost of financial resources, cost of processing accounting data and error rates.	Variance analysis on hiring and firing, cost of recruitment, composition of skills inventory, cost of training, salary paid, distribution of wage rates.
Operational	Hiring and firing of sales force, the day-to-day scheduling of sales and promotion efforts and periodic analysis of sales volumes by region, product, customer, etc.	Reports comparing actual performance to production schedule and highlighting areas where bottlenecks occur.	Daily error and exception reports, records of processing delays, reports of unprocessed transactions, etc.	Decision on hiring, training, termination, changing pay rates and issuing benefits.

SYSTEMS CONCEPT OF PRODUCTION/OPERATION

System is a collection of interrelated entities.

Inputs to the system are

Materials

Labour

Equipment's

Capital.

The types of inputs used vary from one industry to another.

These inputs are combined and converted into goods and /or services by a suitable process technology.

Figure below explains the systems aspect of production/operation function of an organisation.

Organization receives several inputs on LHS and converts them into useful products/services using the facilities (manufacturing facilities). To cope up the deviations arise (quality, size, shape / no. of units produced), Feedback is essential and putted to the input stage for making necessary corrections.

A sample list of corrections is presented below:

Tight quality check on the incoming raw materials.

Adjustment of machine settings.

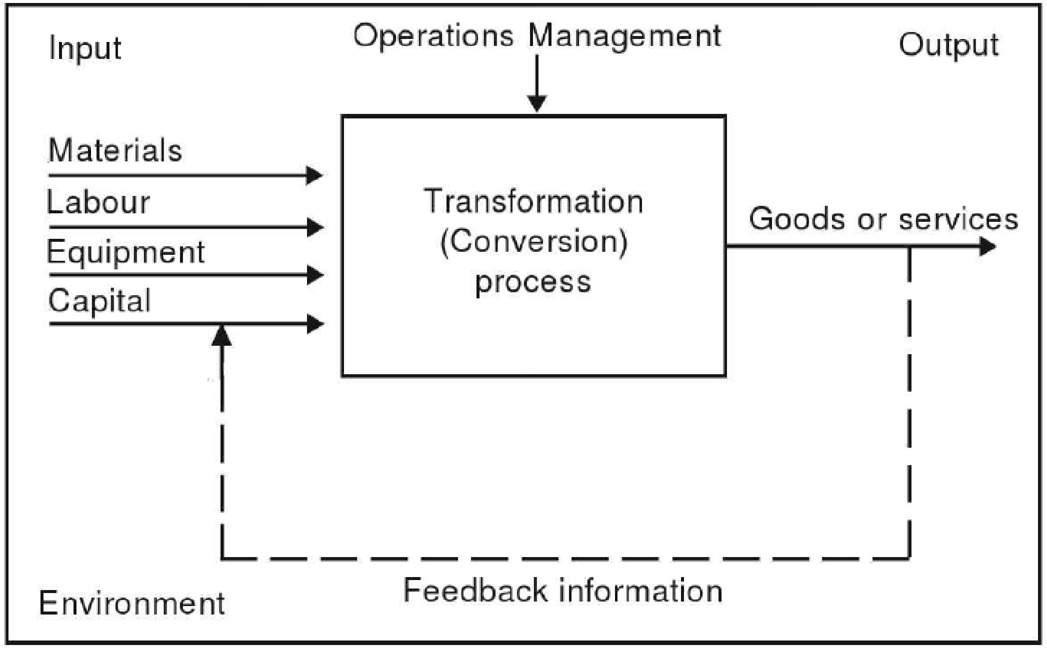
Change of tools.

Proper allocation of operators to machines with matching skills.

Change in the production plans like increase or decrease in volume of production.

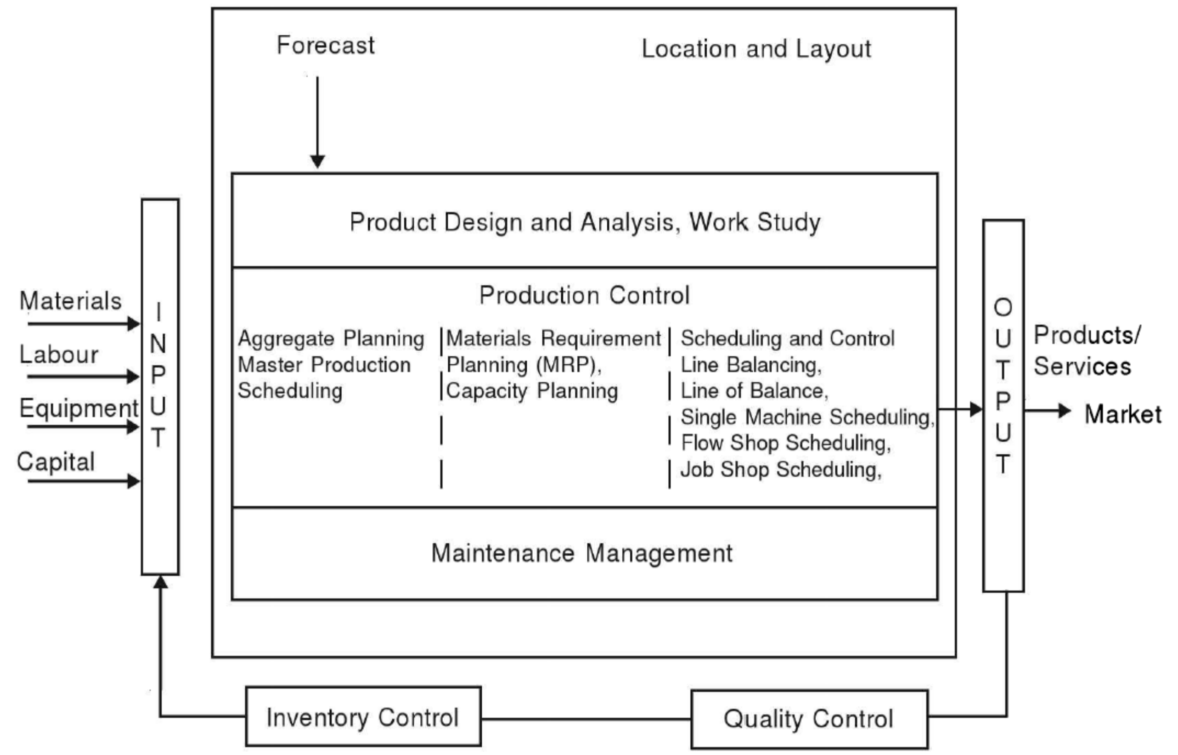
Rigid in-process quality performance to avoid rework.

Based on this feedback, the system once again tries to produce the product/service with modified parameters, in order to meet the specifications. The feedback mechanism is a continuous exercise to monitor the status of the system. The system operates in an environment. So, the system has to take feedback from its environment and adjust its parameters accordingly. The environment can be classified into internal environment and external environment. The top management may be treated as the internal environment and its instructions and expectations will form internal feedback. The system must respond to these modifications for achieving better results.



System aspects of production/operation function

A detailed schematic diagram of the production/operations subsystem is shown in figure below, wherein the different components of the production/operations system are indicated. This system receives different inputs as indicated in the figure and converts them into useful products/services by utilizing the equipment at the transformation stage. This is usually achieved with the help of required manpower and by applying suitable techniques and procedures.



Schematic representation of production/operations subsystem

The techniques and procedure used in the production/operations system are as follows:

1. Forecasting
2. Location and Layout techniques
3. Product Design and analysis, work study
4. Production control techniques
    (a) Aggregate planning
    (b) Master Production Schedule
    (c) Materials requirements planning
    (d) Capacity planning
    (e) Scheduling and control
        - Line Balancing

    - Line of balance
    - Single machine scheduling
    - Flow shop scheduling
    - Job shop scheduling
5. Maintenance Management
6. Feedback and control techniques
    (a) Quality Control
    (b) Inventory Control

The finished product/services produced by the system are to be checked for conformance with quality specifications and other design specifications. These are done at the output stage and corresponding feedback are given to the input stage for necessary corrections. This feedback mechanism is a continuous process, but the degree of corrections required depends on the materials quality, equipment’s condition, employees’ skill and their commitments.

Trends in Operations Management

1. Industry 4.0

Industry 4.0 represents the fourth industrial revolution, where digital technologies are integrated with manufacturing and operations to create smart and connected systems.

Key Technologies:

- Internet of Things (IoT)
- Cyber-Physical Systems (CPS)
- Big Data analytics
- Cloud computing
- Automation and robotics

- Digital twins

Impact on Operations:

- Real-time production monitoring
- Predictive maintenance
- Mass customization
- Improved productivity and quality

2. Sustainability in Operations

Sustainability in operations focuses on environmentally and socially responsible production while maintaining economic viability.

Key Aspects (Triple Bottom Line):

- **Economic:** Cost efficiency, long-term profitability
- **Environmental:** Reduced emissions, energy efficiency, waste minimization
- **Social:** Worker safety, ethical sourcing, community impact

Sustainable Practices:

- Lean and green manufacturing
- Use of renewable energy
- Sustainable supply chain management
- Recycling and circular economy models

Benefits:

- Compliance with regulations

- Cost reduction
- Enhanced corporate image

3. Artificial Intelligence (AI) in Operations

AI involves the use of machine learning, data analytics, and automation to improve operational decision-making and efficiency.

Applications:

- Demand forecasting
- Inventory optimization
- Predictive maintenance
- Quality inspection using vision systems

- Production scheduling

Advantages:

- Faster and more accurate decisions
- Reduced operational costs
- Increased efficiency and flexibility

Basics of Operations Research (OR) and Its Application in Decision-Making

Introduction to Operations Research

Operations Research (OR) is a scientific and quantitative approach to decision-making that seeks to determine the best possible course of action in complex situations. It uses mathematical models, statistical analysis, and optimization techniques to analyze systems and improve efficiency, productivity, and effectiveness.

OR is widely used in engineering, management, economics, defense, healthcare, transportation, and manufacturing.

Objectives of Operations Research

The main objectives of OR are to:

- Optimize the use of **limited resources** (men, machines, materials, money)
- Minimize **costs, time, or risks**
- Maximize **profit, efficiency, or service level**
- Support **rational and scientific decision-making**

Basic Features of Operations Research

- **System orientation**: Considers the entire system rather than isolated parts
- **Interdisciplinary approach**: Combines mathematics, statistics, economics, and engineering
- **Model-based analysis**: Uses mathematical and simulation models
- **Optimization focus**: Seeks the best solution among alternatives
- **Data-driven**: Relies on quantitative data and analysis

Steps in Operations Research Methodology

1. **Problem formulation** – Clearly define the decision problem
2. **Model construction** – Develop a mathematical or logical model
3. **Data collection** – Gather relevant and accurate data

4. **Model solution** – Apply appropriate OR techniques
5. **Validation** – Check model accuracy and reliability
6. **Implementation** – Apply the solution in real situations
7. **Monitoring and control** – Review and update the solution if needed

Common Operations Research Techniques

Some widely used OR techniques include:

- **Linear Programming (LP)** – Optimal allocation of resources
- **Transportation and Assignment Models** – Cost-effective distribution and task allocation
- **Queuing Theory** – Analysis of waiting lines
- **Inventory Models** – Optimal stock levels

- **Game Theory** – Competitive decision-making
- **Decision Theory** – Decisions under certainty, risk, and uncertainty
- **Simulation** – Modeling complex real-world systems
- **Network Models (PERT/CPM)** – Project planning and scheduling

Table: Major OR Techniques (with purpose)

Technique	**Application**
Linear Programming (LP)	Optimal resource allocation
Transportation Model	Minimum-cost distribution
Assignment Model	Best task-to-person allocation
Queuing Theory	Waiting line problems
Inventory Models	Stock level optimization

Game Theory	Competitive decision-making
Decision Theory	Decisions under risk/uncertainty
Simulation	Complex system analysis
PERT / CPM	Project planning & scheduling

Role of Operations Research in Decision-Making

OR plays a crucial role in decision-making by:

- Providing a **scientific basis** for decisions
- Evaluating **multiple alternatives** objectively
- Reducing **uncertainty and risk**
- Improving **accuracy and consistency** in decisions

- Supporting **strategic, tactical, and operational decisions**

Applications of Operations Research in Decision-Making

a) Business and Management

- Production planning and scheduling
- Supply chain and logistics optimization
- Marketing strategy and pricing decisions

b) Manufacturing and Engineering

- Machine utilization and maintenance planning
- Quality control and process optimization

c) Transportation and Logistics

- Route optimization
- Fleet management

d) Healthcare

- Hospital resource allocation
- Staff scheduling and patient flow management

e) Defense and Public Systems

- Military logistics and strategy planning
- Disaster management and emergency response

f) Finance

- Portfolio optimization

- Risk analysis and capital budgeting

Advantages of Operations Research

- Improves **decision quality**
- Ensures **optimal use of resources**
- Enhances **organizational efficiency**
- Reduces operational costs
- Supports long-term planning

Limitations of Operations Research

- Depends on **accurate data and assumptions**
- Complex models may be difficult to understand

- High computational and implementation cost
- Human and qualitative factors may be overlooked

Operations Research is a powerful tool that transforms decision-making from intuition-based to **scientific and systematic**. By applying OR techniques, organizations can achieve optimal solutions, improve efficiency, and make better decisions in complex and uncertain environments.

MODULE II

Module-II Production & Operation Systems (09 Hours)

Types of production systems: job shop, batch production, mass production, continuous flow. Characteristics, advantages, and limitations of each system. Automation in production: types, role of robotics and IoT. Overview of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). Facility location decisions: qualitative and quantitative models, break-even analysis. Capacity planning: definition, types (design, effective, actual), tools and capacity requirement planning (CRP).

TYPES OF PRODUCTION SYSTEM

The production system of a company mainly uses facilities, equipment's and operating methods (called the production system) to produce goods that satisfy customers demand. The above requirements of a production system depend on the type of product that the company offers and the strategy that it employs to serve its customers. The classification of production system is summarized in Table below and is explained in the following sections.

Production systems refer to the methods and processes used to produce goods and services. They can be broadly classified into several types based on the nature of the production process, volume, and variety of products.

Here are the **main types of production systems**:

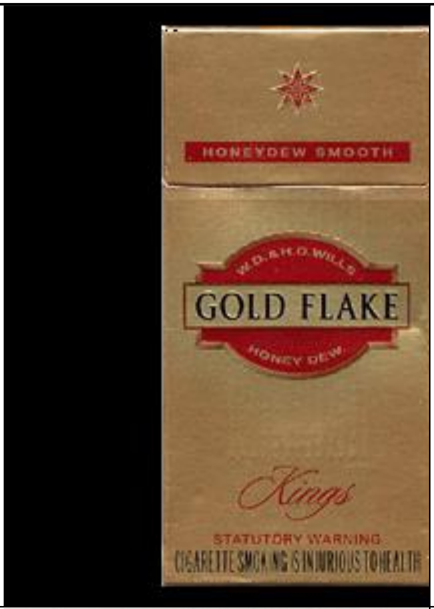
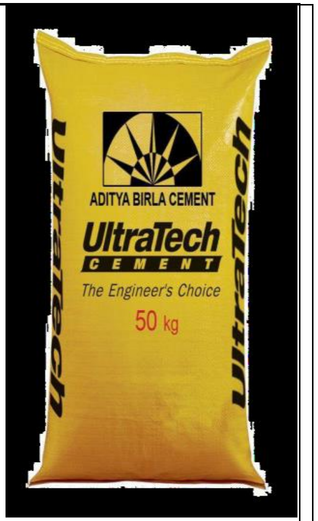
Table: Clasification of Production System

Basis	Classifications	Examples
Types of output	Products	Consumer goods like furniture, TV, radio etc. Producer goods like lathe, milling machine etc.
	Services	Transportation, health, entertainment, banking services, education system etc.
Types of flow	Projects	Construction of bridge, dam, road etc.
	Job shop	Hospital, auto repair, machine shop, furniture company etc.
	Flow shop	High volume TV factory, auto factory etc.

Types of specification under service type	Continuous process	Postal services, telephone company, power corporation, oil refinery, chemical plant
	Customized	Medical care, legal services
	Standardized	Insurance, wholesale stores

1	**Flow shop (Mass Production)**	Producing large volumes of standardized products using assembly lines. (Successive units of output undergo same sequence of operation using specialized equipment positioned along a production line.) Examples- Auto assembly, assembly of television sets,

		assembly of electric motors, packaged foods smart phones assembly of keyboards. **Features**: ○ High efficiency ○ Low unit cost ○ Less flexibility ○ Requires heavy investment in machinery

		    
2	**Continuous Production** /continuous	Extreme flow shop is treated as a **Continuous Production** /continuous process (An uninterrupted, 24/7 production system for highly standardized products) in which there is constant flow of materials, as in

	process	Example- Oil refining, Chemical processing Electric generation **Features**: • Very high volume • Automated and efficient • High initial investment • Minimal human intervention

3	**Job shop Production**	**Definition**: Producing a single product or a **small batch of different products based on specific customer requirements.** • In this system, products are made according to specific customer orders. Each product requires unique processing, and the workflow is flexible to accommodate varying specifications. • This is conversation process in which units of different types of products follow different sequences through different shops. • This system has more flexibility but this system results into more set-up time, more in-process inventory, complex scheduling, varying quality and so forth. **Examples**: • Custom furniture,

		- Tailored suits,
		- Shipbuilding.
		- **Features**:
		  - High customization
		  - Skilled labour
		  - High unit cost
		  - Low production volume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4	**Batch Production:**	Here, products are produced in groups or batches. Batch manufacturing produces some intermediate varieties of products with intermediate volume. Volume of any single product may not be sufficient to justify the use of a dedicated set of equipment's for its production. Under this condition a few or several products will have to share the production resources to balance their utilization. Each batch goes through the whole production process before moving to the next stage. It allows for moderate customization while benefiting from economies of scale within each batch. Production equipment in batch manufacturing must be capable of performing

		a variety of tasks, but the range of possible operations is much narrower than in a job shop. **Examples**: Bakery items, clothing, pharmaceuticals. **Features**: • Moderate volume • Flexibility in product variety • Downtime between batches • Lower cost per unit than job production
	Project-Based	• A project refers to the process of creating a complex one of a kind product/ service with a set of well-defined tasks in terms of resources

	Production	required and time phasing. • **Definition**: Production of a one-time, large-scale project typically carried out on-site. • **Examples**: Construction of bridges Dams, Software development. • **Features**: ○ Long duration ○ Unique output ○ High planning and coordination ○ High cost

FACILITY LOCATION

Introduction

Business systems utilize facilities like plant and machineries, warehouses etc while performing the task of producing products/services.

Proper planning of these facilities would definitely reduce their cost of operation and maintenance.

Plant location decisions are very important because they have direct bearing on factors like financial, employment and distribution patterns. In long run, relocation of plant may even benefit the organisation but on the other hand involves stoppage of production and also cost for shifting facilities to a new location, which introduce inconvenience in the normal functioning of the business.

Hence at the time of starting an industry, one should generate several alternate sites for locating the plant.

After critical analysis, the best site is to be selected for commissioning the plant.

Reasons for Plant Location Study

The following events are quite common in any business venture.

Establishment of a new venture.

Expansion of existing business.

Significant change in existing demand supply and marketing locations.

Significant change in the cost structure.

Government policies.

Because of these events, an organization will be keen in additional or alternate sites for its production activities. So the plant location becomes an important decision which in turn influences plant layout and facilities needed. Also it influences capital investment and operating costs.

For example, in steel industry, if we integrate the units from ore extraction to final steel formation in a nearby area, the transportation cost would be substantially reduced and also, the reliability of supplies to the final stages of production in the integrated plant would be improved. This in turn, improves the productivity of the plant.

What is Facility Location?

Facility Location refers to the process of identifying the most suitable geographical site for a company's operations—such as a factory, warehouse, retail store, or office.

Definition: Facility location is the strategic process of determining the best physical location for a facility to optimize operational efficiency, minimize costs, and maximize service to customers.

Objectives of Facility Location:

1. **Minimize cost** (transportation, labour, utilities, etc.)
2. **Maximize customer service** and accessibility
3. **Ensure smooth supply chain and logistics**
4. **Support business growth and expansion**
5. **Leverage local advantages** (e.g., tax benefits, skilled labour, infrastructure)

Factors Influencing Facility Location:

The factors which influence plant location can be classified into General Factors and specific Factors.

General Factors

1. Availability of land for present and future needs and cost of land and land development and building etc.
2. Availability of inputs such as labour, raw materials etc.
3. Closeness to the market places.
4. Stability of demand.
5. Availability of communication facilities.
6. Availability of necessary modes of transportation like road, rail, airport and water ways.
7. Availability of infrastructure facilities such as power, water, financial institutions, banks etc.

8. Disposal of waste and effluent and their impact on the environment.
9. Government support, grant, subsidy, tax structure.
10. Availability of housing facilities and recreational facilities.
11. Demographic factors like population, trained manpower, academic institutions, standard of living, income level etc.
12. Security, culture of society.
13. Fuel cost.

Specific Factors

Desiring to set up plant should consider the following aspects in addition to the normal factors.

1. Economic stability of the country and the concern of the country towards outside investments are to be considered.
2. The success of operation of the factory depends on the cultural factors, language and cultural differences which can present operating, control and even policy problems. Units of measurement is also very important in international business.
3. Analysis must be based on the factors like wage rate, policy, duties etc.
4. The company can setup joint venture with any leading local giants that will solve many operational problems.

Factor	Explanation
Proximity to market	To reduce delivery time and improve customer service
Access to raw materials	To minimize transportation cost and ensure timely supply
Availability of labour	To access skilled and affordable workforce
Transportation facilities	Efficient road, rail, port, or air connectivity

Factor	Explanation
Infrastructure	Power, water, internet, and waste disposal
Government policies	Tax incentives, legal regulations, industrial zones
Environmental impact	Pollution control, sustainability, and legal compliance
Land cost and availability	Affordability and suitability of land

Example: A manufacturing company may choose to set up a plant in an industrial zone close to:

- Suppliers of raw materials
- Major highways or railroads
- Markets for finished goods
- An area with low labour costs.

Facility Location Decisions

Purpose: To choose the best location for a facility (factory, warehouse, retail unit, etc.) to balance cost, convenience, and operational efficiency.

1. Quantitative Models

These are **mathematical, data-based models** used to evaluate alternatives objectively.

Model	**Description**	**Key Features**
Factor Rating Method	Scores locations based on weighted factors	Simple, flexible, widely used
Center-of-Gravity Method	Finds central location to minimize transportation cost	Useful for warehouses or distribution centers
Load-Distance Method	Calculates weighted distance between sources and facility	Minimizes travel distance or time

Model	Description	Key Features
Break-even Analysis	Compares fixed and variable costs of different sites	Helps in cost-volume analysis
Transportation Model	Optimizes shipping costs from multiple sources to destinations	Linear programming approach

2. Qualitative Models

These involve **subjective assessments** based on experience, judgement, and strategic fit.

Model	Description	Used When
Delphi Method	Group of experts reach consensus through rounds of questioning	When factors are uncertain or subjective

Model	**Description**	**Used When**
SWOT Analysis	Evaluates Strengths, Weaknesses, Opportunities, and Threats of locations	Strategic-level decision-making
Checklist Approach	Uses a checklist of required criteria	Quick screening of location suitability
4. Location Rating Scales	Rates qualitative features like lifestyle, climate, laws, etc.	Evaluates intangible factors

ON

Break Even Analysis

Relation ship betn
Total cost of product
Total selling cost of product
Total volume of production

Break-even point

Where $\boxed{T.C = T.S.C}$ (No profit, No loss point)
from where profit started

Decision rule

Break-even analysis is a financial tool used to determine the level of sales or production at which a business neither makes a profit nor incurs a loss. It identifies the point at which/where total revenue equals total costs (fixed + variable), known as Break-even point.

Assumption ⇒

(I) Total cost = Fixed cost + Variable Cost
divided into two parts

(II) Fixed cost is always constant at all point. (whether single product or multi product)

(III) Variable cost directly vary or proportional with volume of production. (no discount applicable)
(∴ with quantity ↑, variable cost ↑)

OM

(IV) Selling cost / Unit is always constant

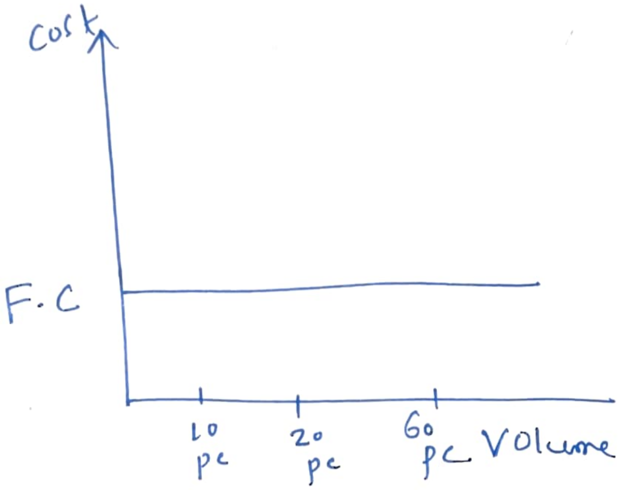
(V) product produced ⇒ all will be sold.

(VI) Plant deals with only one product.

Break even analysis ?

Total cost = Fixed cost + Variable cost

Fixed cost ⇒



At any quantity
F.C is same.

m/c cost .

Higher officers salaries. Electricity bill,

workers, staff salaries, Outsource labour.

Whether plant will run/not.

cutting fluid, lubricant, grease cost .

~~Direct labour~~.

~~Direct material~~.

OM

-: Fixed cost refers to that cost that doesnot change with the level of production/sales within a certain range.

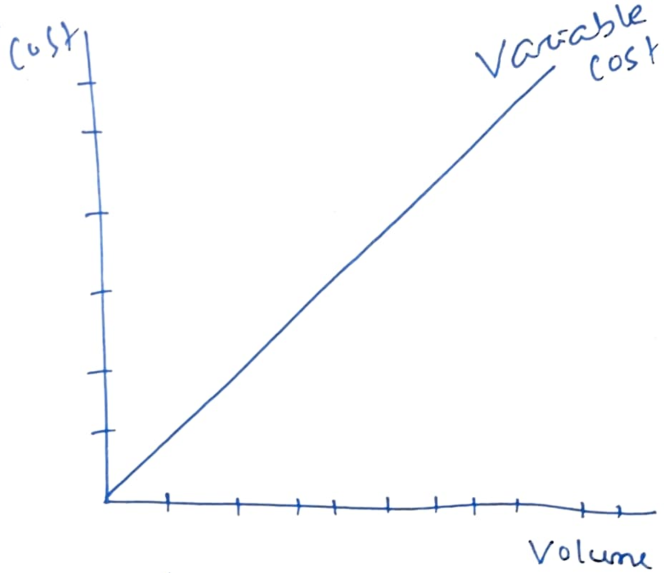
It remains constant regardless of how much a company produces or sales in the short term.

ex → { rent of a factory or office.
- Salaries of permanent staff
- Depreciation of machinery.
- Insurance
- Property taxes.
- Electricity bills, phone bills, water bills.

Incurred even at zero output

Not affected by prodⁿ volume

Variable Cost ⇒



(Direct Labour.
Direct material)

OM

Variable Cost is the cost that changes directly with the level of production/sales, in break even analysis. Variable costs are crucial because they affect the Contribution margin, which is used to calculate the break even point.

Example: Direct Labour (based on units produced)

Raw material.

Packaging

Shipping

~~Utilities Utilities tied t~~

utilities tied to $prod^n$.

Total Variable cost = $x \cdot V.C/unit$
V.C

↳ No. of product

[ex:- Let $V.C/unit = 10$

Let $x = 100$ pc we need to produce.

Then Total $V.C = x \times V.C/unit$

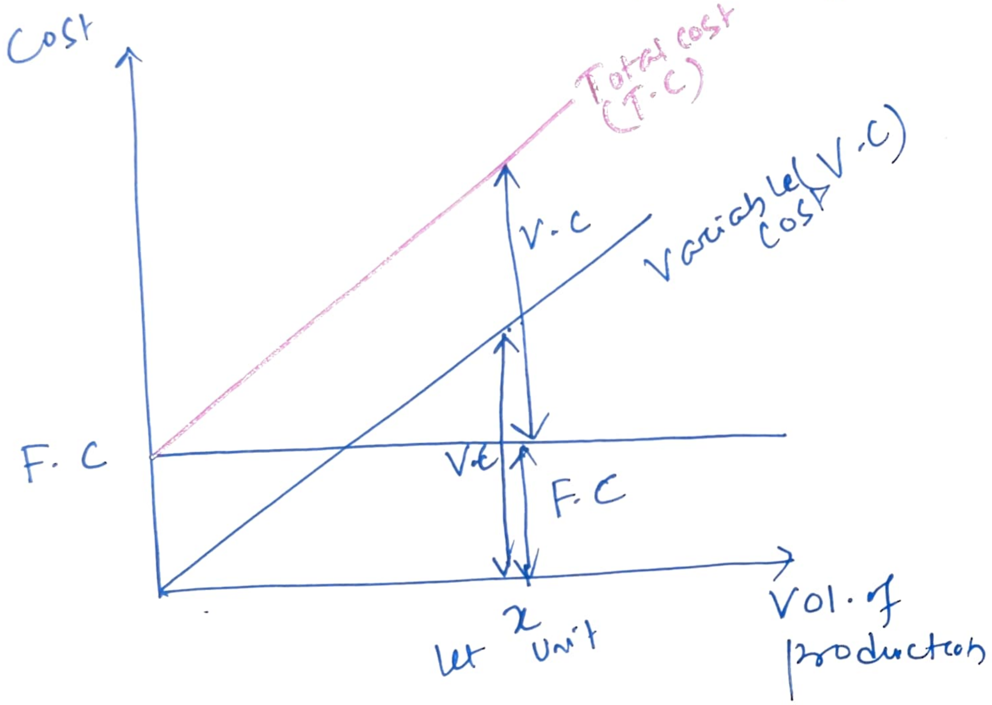
$= 100 \times 10$

$\therefore V.C = 1000$]

Total Cost = Fixed Cost + Variable Cost

$$\boxed{T.C = F.C + x \cdot V.c/\text{unit}}$$

Where x = No. of unit produced.



Break-even analysis is the process of calculating the point at which total revenues & total costs are equal, resulting in neither profit nor loss.

OM

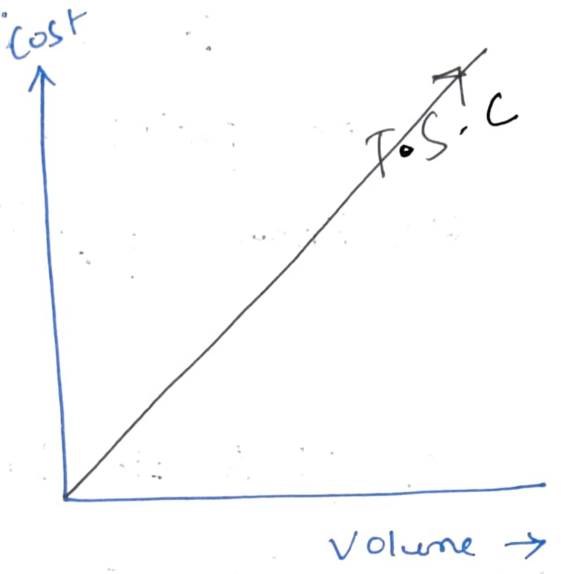
Total Selling Cost ⇒

$\boxed{TSC \Rightarrow T.C + Profit}$

Total cost

P

Total selling cost



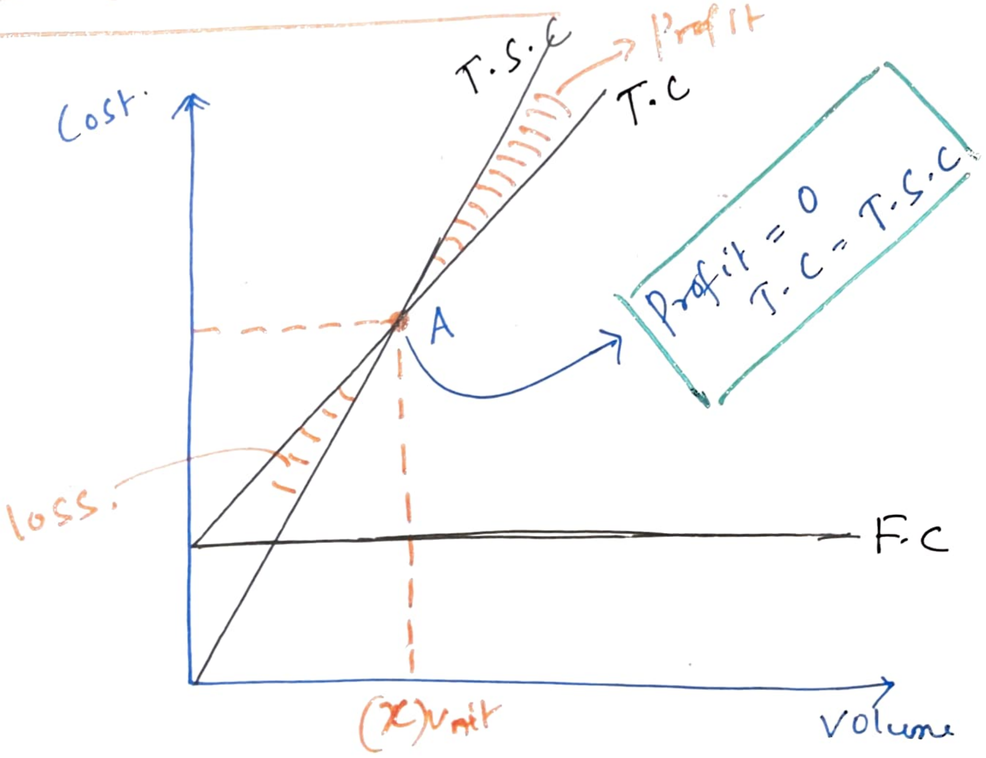
Selling cost

Total selling cost = selling cost/unit × no. of units to sell ~~to~~ | ~~produce~~ ~~purchase~~

or no. of unit to sold

$\boxed{T.S.C = x \times S.C/unit}$

BREAK-EVEN POINT ⇒



OM

At point A   Total cost = Total selling cost

$$T \cdot C = T \cdot S \cdot C$$

ie profit = zero

We know the formula is $\cancelto{0}{\text{Profit}} + \text{Total cost}$

$= \text{Total selling cost}$

∴ pt A ⇒ Break-even point

Above 'A'   Profit

Below 'A'   loss

$$\text{Total selling cost} = \text{Total cost} + \cancelto{0}{\text{Profit}}$$

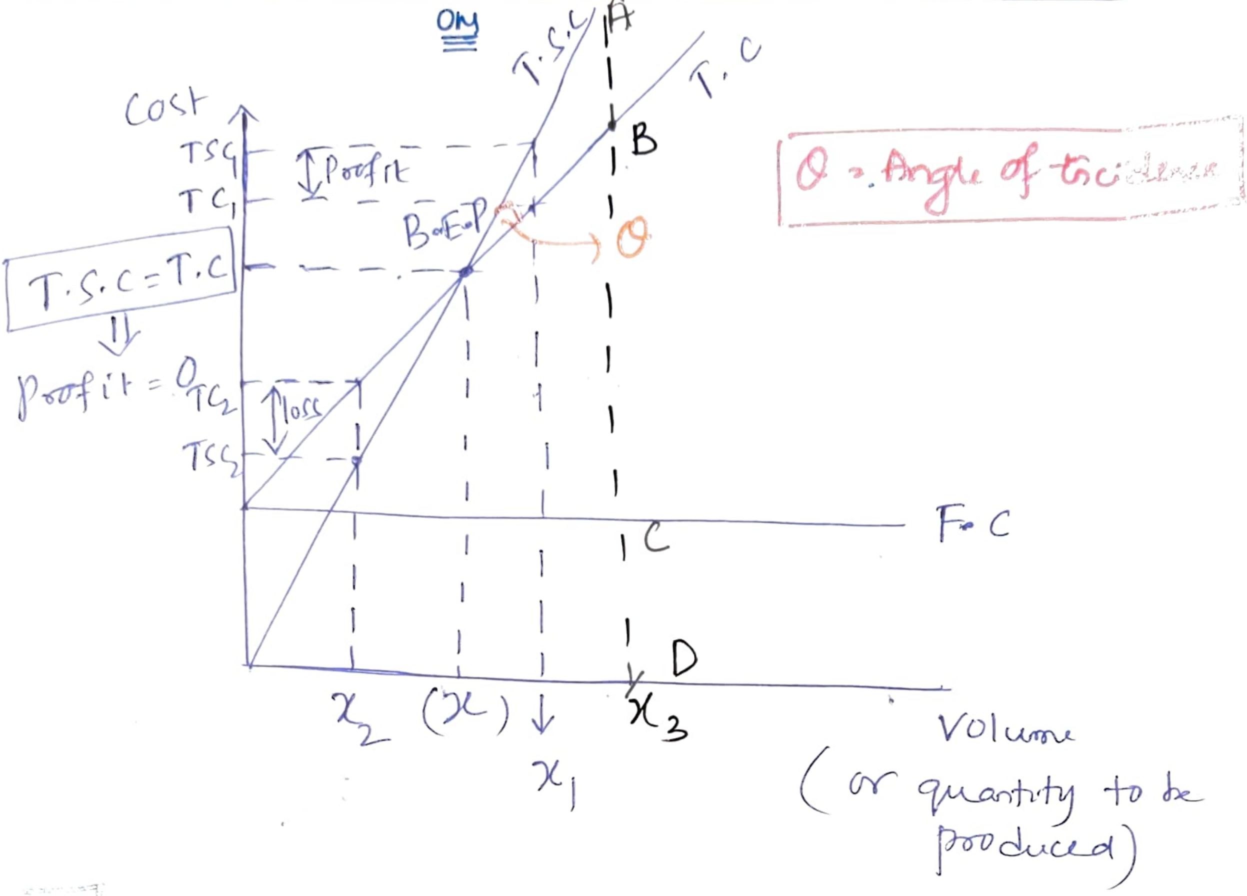
At Breakeven pt   Profit = 0

$$\therefore x \times S.C/\text{unit} = F.C + x \cdot V.C/\text{unit}$$

$$\Rightarrow \boxed{x = \frac{F.C}{\left(S.C/\text{unit} - V.C/\text{unit}\right)}}$$

Break-even quantity

This is the quantity upto which ~~profit~~ no loss we need to sell the product and after that we can able to get the profit.



θ = Angle of incidence

θ = Angle of incidence

θ must be high ↑

T.S.C slope high

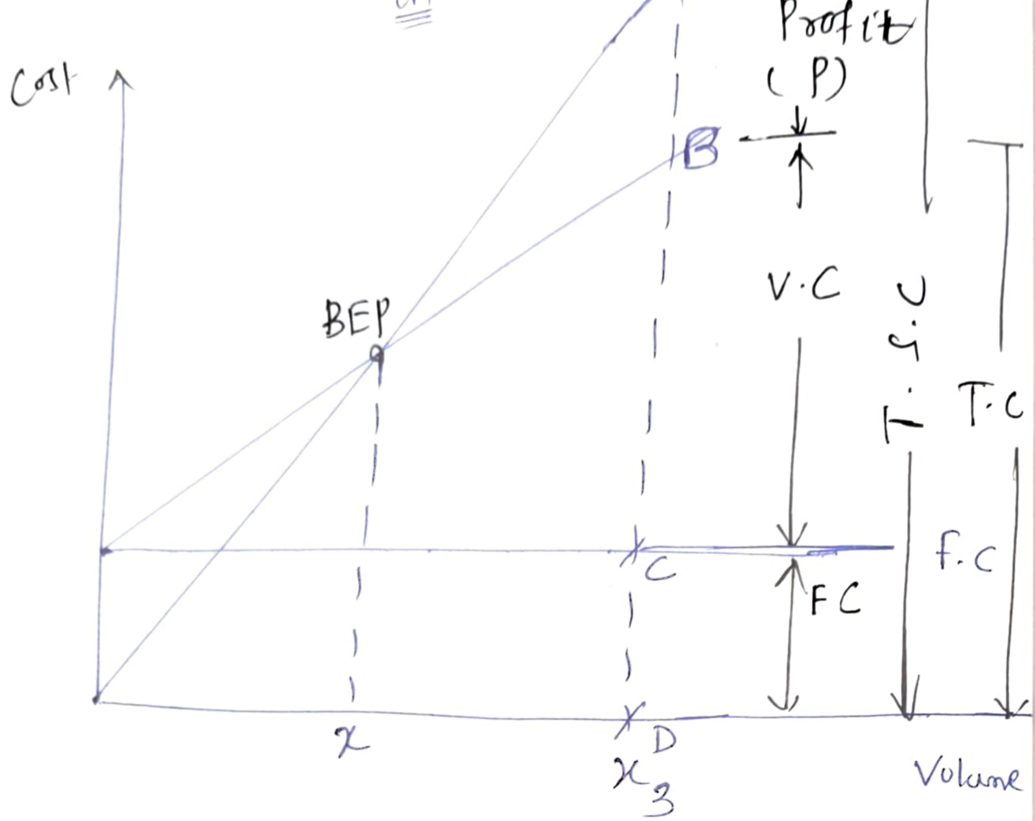
T.C slope low

$$\boxed{\text{If } \theta \uparrow \Rightarrow \text{Rate Profit} \uparrow}$$

$$\boxed{\underset{\text{(MOS)}}{\text{Margin of Safety}} = x - (x)_{BEP}}$$

$$* \quad x = \frac{F.C}{\text{Contribution/unit}}$$

where $\boxed{\text{Contribution/unit}} = S.C/_{unit} - V.C/_{unit}$.



At any point x_3, cost is shown such a
F.C, V.C, T.C, TSC & P.

* Contribution margin = AB + CD
(Gross profit) = P + F.C

In order to gain the profit, every one wants BEP must come early so that profit can be gained very earlier.

So in order to decrease x ↓, three factors are their F.C, S.C/unit & V.C/unit.

$$\downarrow \; x = \frac{F.C}{S.C/unit - V.C/unit}$$

to decrease $x \downarrow$ to achieve B.E.P earlier ⇒

F.C ⇓

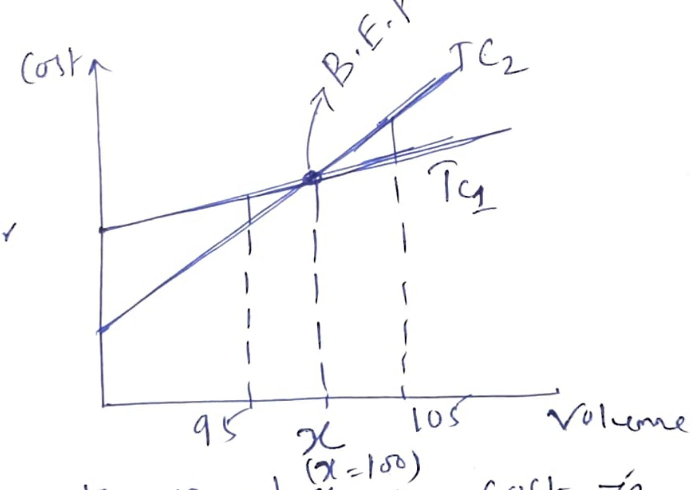
S.C/unit ⇑

V.C/unit ⇓

Decision Tool ⇒

Product 1 ⇒ $T.C_1$ by process I

Product 2 ⇒ $T.C_2$ by process II



For ex: $x = 100$ no. of products. So if no. of product reqr is more than 100, then we can opt TC_1 i.e process I to produce the product as cost is less, but if no. of product reqr is less than 100, then process II is feasible as cost reqr to produce by process II is less. Accordingly decision is taken.

OM

Q.4 Last year, a manufacturer produced 15000 products which were sold for Rs 300 each. At that volume, the fixed cost were Rs 15.2 Lacs & total variable cost were Rs 21 Lacs. The breake even quantity of product would be :

(A) 4000 (B) 7800 (C) 8400 (D) 9500

S.C / unit = 300

F.C = 15.2 Lacs.

V.C = 21.0 Lacs

$$B.E.Q = \frac{F.C}{S.C/\text{unit} - V.C/\text{unit}}$$

$$V.C/\text{unit} = \frac{21.0 \times 10^5}{15000} = \underset{Rs.}{140} / \text{unit}$$

$$BEP = \frac{15.2 \times 10^5}{300 - 140}$$

x = 9500 (Ans)

(option D)

OM

Q.1 A manufacturer has the following data regarding a product:

Fixed cost per month = Rs 50000

Variable Cost per unit = Rs 200

Selling price per unit = Rs 300

Product capacity = 1500 unit per month

If the production is carried out at 80% of the rated the capacity, the monthly profit (in Rs) is ________.

Profit = Total Selling cost – Total cost

$$\Rightarrow \boxed{P = T.S.C - T.C}$$

No. of product produced per month

$= 0.8 \times 1500$ ($\because$ given production is carried out at 80% of the rated capacity)

$= 1200$ /month

$\therefore$ $T.S.C = 1200 \times 300$

$= 360{,}000$

$T.C = F.C + V.C$

$= 50{,}000 + 200 \times 1200$

$= 2\,90{,}000$

OM

$\therefore$ P = T.S.C − T.C

= 360,000 − 290,000

= 70,000 Rs.

Q2 A component can be produced by any of the four processes I, II, III and IV. The fixed cost & the variable cost ~~of~~ for each of the processes are listed below. The most economical process for producing a batch of 100 pieces is

Process	Fixed cost (in Rs)	Variable cost per piece (in Rs)
I	20	3
II	50	1
III	40	2
IV	10	4

No. of pieces = 100

Total cost = F.C + V.C

Process I T.C = 20 + 3 × 100 = 320

II T.C = 50 + 1 × 100 = 150 4
(min

III T.C = 40 + 2 × 100 = 240

IV T.C = 10 + 4 × 100 = 410

OM

Mam   Process II

Q.3 A standard m/c tool and an automatic m/c tool are being compared for the production of a component. Following data refers to the two m/cs.

	Standard m/c tool	Automatic m/c tool
Set up time	30 mins	2 hours
machining time per piece	22 min	5 min
machine rate	Rs 200 per hr	Rs 800 per hours

The breakeven production batch size above which the automatic m/c tool will be economical to use the

(a) 4   (b) 5   (c) 24   (d) 225

Standard m/c tool

Set up cost is nothing but F.C as once m/c is set up then we can start work on that m/c.

So F.C = $\left(\frac{30}{60}\right) \times 200$ = F.C in Rs.

→ (in hr)

machining time per piece = $\left(\frac{22}{60}\right) \times 200$ Rs

in hr per piece

OM

Let 'x' unit to be produced.

∴ Total cost = F.C + V.C

$$(T.C)_1 = \left(\frac{30}{60}\right) 200 + \left(\frac{22}{60}\right) 200 \times x \quad \text{—(i)}$$

for Standard m/c tool

Similarly for automatic m/c tool

Total Cost = F.C + V.C (in similar way)

$$(T.C)_2 = 2 \times 800 + \left(\frac{5}{60} \times 800\right) x \quad \text{—(ii)}$$

For B.E.P

$$(T.C)_1 = (T.C)_2$$

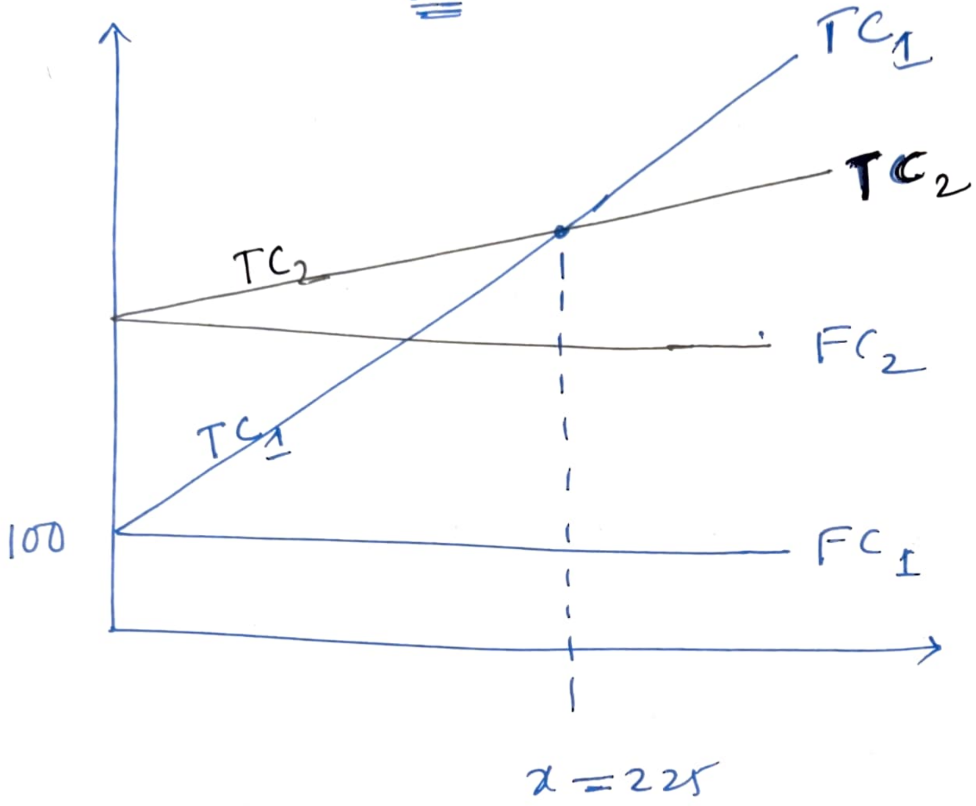
$$\frac{1}{2} \times 200 + \left(\frac{22}{60}\right) 200x$$

$$= 2 \times 800 + \left(\frac{5}{60} \times 800\right) x$$

⇒

⇒ $x = 225$

OM



From this graph, we can also revealed that if we want to produce $x < 225$ then we will opt process 1 as TC 1 is less than TC_2.

But if $x > 225$ we will opt, [illegible] process II as TC_2 is less than TC 1 after ~~225 produce~~ $x = 225$.

Capacity planning: definition, types (design, effective, actual), tools and capacity requirement planning (CRP).

- Capacity planning is a crucial aspect of operations management, aimed at ensuring that a business has enough capacity (resources, facilities, etc.) to meet current and future demands efficiently.

Capacity planning involves determining the capacity required by an organization to meet changing demands for its products or services. It ensures that the organization can meet customer demand without over- or under-utilizing resources.

or

Capacity planning in **Production and Operations Management (POM)** is the process of determining the production capacity needed by an organization to meet changing demands for its products or services. It ensures that a business can **produce enough output** to satisfy demand **without excessive delays or idle resources**.

Importance / Objectives of Capacity Planning in POM

1. **Meet customer future demand**: Ensure products or services are delivered on time and efficiently.

2. **Optimize resource utilization**: Prevent over- or under- utilization of resources such as labour, machines, space.
3. **Minimize production costs:** Minimize production downtime and operational inefficiencies.
4. **Avoid bottlenecks** in the production system.
5. **Plan for Growth:** Prepare and support future and long-term growth and expansion/ changes in demand.

Types of Capacity Planning

1. **Design Capacity:** This refers to the maximum output that can be achieved under ideal conditions, such as full utilization of resources without any downtime.
2. **Effective Capacity:** This is the capacity that the organization can realistically achieve, considering factors like equipment maintenance, downtime, and employee breaks.
3. **Actual Capacity:** This represents the capacity that the organization achieves in practice, which may vary due to factors such as unexpected downtime, quality issues, or other operational inefficiencies.

The actual output may be even less than the system capacity since it is affected by short-range factors such as actual demand, equipment breakdowns, and personal absenteeism or productivity.

$$\boldsymbol{System\ Efficiency = \frac{Actual\ Output}{System\ Capacity}}$$

Type	Description
Design Capacity	Maximum output under ideal conditions (theoretical limit).
Effective Capacity	Expected output under normal working conditions (accounts for maintenance, breaks, etc.).
Actual Capacity	The real output achieved over time (includes inefficiencies, breakdowns).

Tools/Techniques for Capacity Planning

1. Capacity Requirement Planning (CRP):

- CRP is a technique used to determine the amount of capacity needed to meet future production requirements. It considers factors like customer demand forecasts, lead times for materials, and production schedules.
- It is a detailed process to determine **work center capacity** needs based on the **Master Production Schedule (MPS)** and **Bill of Materials (BOM)**.
- Helps identify **over-loaded or under-loaded** resources.
-

2. **Rough-Cut Capacity Planning (RCCP):**
    - Early-stage capacity check based on **aggregated data**.
    - Used before CRP to ensure **feasibility of master schedules**.
3. **Overall Equipment Effectiveness (OEE):**
    - Measures equipment performance based on **availability, performance, and quality.**
4. **Simulation Modeling:** Simulation modeling is used to analyse different capacity planning scenarios by creating virtual models of the production process.

It helps in evaluating the impact of changes in demand, resource constraints, and production schedules.

Virtual modeling of operations to test different capacity strategies.

5. **Resource Planning Software**: Various software tools are available to assist in capacity planning, including enterprise resource planning (ERP) systems and specialized capacity planning software.

These tools help in modeling different scenarios, optimizing resource allocation, and forecasting capacity needs.

ERP Software (like SAP, Oracle) Integrated tools for tracking and planning capacity across departments.

Steps in Capacity Planning Process

1. **Forecast Demand** → Estimate future product or service needs.
2. **Determine Capacity Available** → Analyse current resource capability.
3. **Identify Gaps** → Compare available capacity vs. required capacity.
4. **Develop Alternatives** → Add shifts, outsource, purchase new machines, etc.
5. **Evaluate and Select Best Option** → Cost-benefit analysis.
6. **Implement and Monitor** → Execute the plan and track performance.

Capacity Planning Strategies

Capacity is a measure of the ability to produce goods and services or, it may be called as the rate of Output.

Capacity Planning is the task of determining the long- and short-term capacity need of an organization and then determining how these needs will be satisfied.

LONG TERM CAPACITY STRATEGIES:

Top management may have the following strategies to cope up with major changes in products and services that it can provide to customers in the **long run** which will have significant impact on the capacity. The major changes will altogether revise the demand and resource requirements.

These are:

- Develop new product lines
- Expand existing facilities.
- Construct or phase out production plants.

Technological obsolescence may force some industries to use phase-in strategy for introducing the next model of the same product or service to retain and/or improve its market segment.

The *phase-in strategy is nothing but the planning for the next model even when the present model is moving well*.

Especially, in electronics industry, any company should do continuous research and development to improve the operational features of the product through advanced technology so that the company will be in a position to bring out products into the market with the latest technology without any time lag.

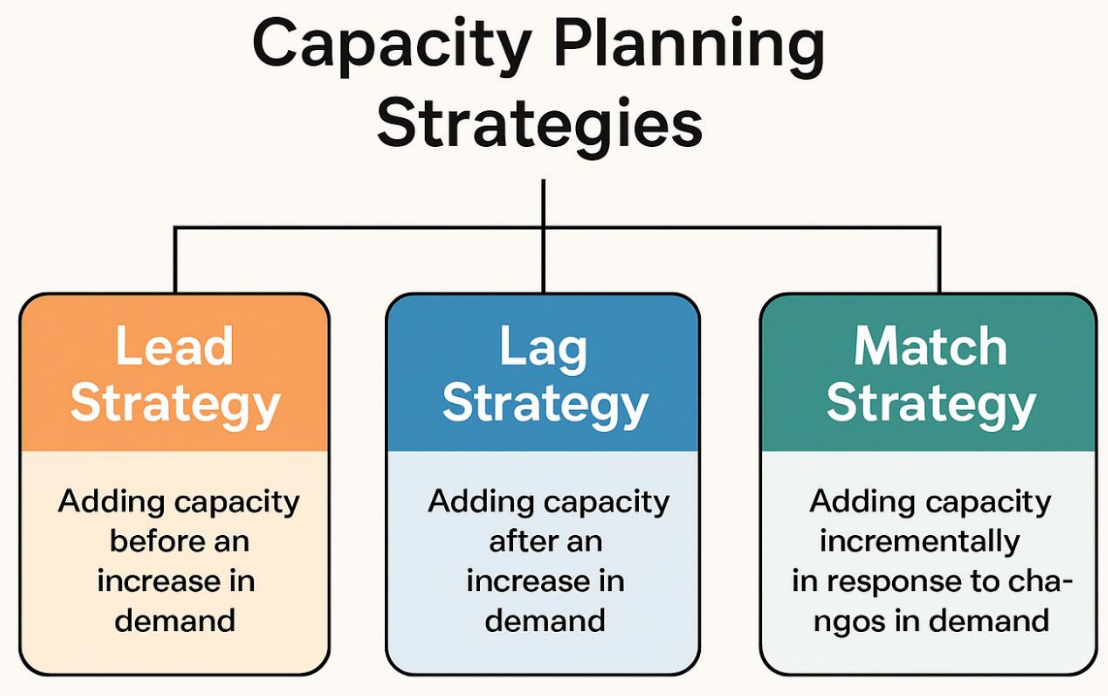
At the same time, all the products will not have continued demand for ever. Moreover, continuing the production of some products will be uneconomical over a period of time. This will force a company to diversify and/or phase out some of the existing products. Phasing out of a product should be done over a period of time properly by taking the re-employment features into account.

SHORT-TERM CAPACITY STRATEGIES:

In short-term planning horizon, capacity decisions are taken by considering the fluctuations in demand caused by seasonal and economic factors. The purpose of short-term capacity planning is to respond to variations in demand during short-term planning horizon.

Strategies like overtime, subcontracting, hiring, firing etc. can be used to cope up with fluctuations in demand.

Another aspects



Types of Capacity Planning Strategies

Capacity planning strategies help organizations align their production capacity with customer demand. The right strategy ensures efficient resource use and prevents both underutilization and overloading. Here are the **three main capacity planning strategies**:

1. Lead Strategy (Proactive Approach)

Definition: Adding capacity **before** the demand actually increases.

Purpose:

- Stay ahead of demand.
- Capture market share.
- Avoid lost sales due to stock-outs.

Advantages:

- Reduces the risk of not meeting demand.
- Helps improve customer service.
- Prepares the firm for sudden demand spikes.

Disadvantages:

- Higher capital investment upfront.
- Risk of excess capacity if demand doesn’t rise as expected.

Best for: Growing markets, competitive industries, or when **first-mover advantage** is critical.

2. Lag Strategy (Reactive Approach)

Definition: Adding capacity **after** the demand has already exceeded current capacity.

Purpose:

- Reduce investment risk.
- Avoid underutilized resources.

Advantages:

- Lower initial cost.
- Capacity expansion only when there is clear demand.

Disadvantages:

- Risk of losing customers due to long waiting times or stockouts.
- May lead to overburdened systems and poor service quality.

Best for: Stable or low-risk markets, or when **cost minimization** is a priority.

3. Match Strategy (Incremental/Hybrid Approach)

Definition:

Adding capacity **in small increments** to match demand trends more accurately.

Purpose:

- Balance between risk and investment.
- Flexibility in responding to market changes.

Advantages:

- Lower risk of over- or under-capacity.
- Flexible and adaptive.

Disadvantages:

- May involve frequent adjustments and planning.
- Medium response time to unexpected demand spikes.

Best for: Moderate growth environments, or when **demand is uncertain or fluctuating**.

Strategy	**Timing**	**Risk**	**Investment**	**Use When**
Lead	Before demand increases	Overcapacity risk	High upfront cost	Demand is growing rapidly
Lag	After demand increases	Lost sales risk	Lower initial cost	Demand is stable or cost is a concern
Match	Gradual/in response to trends	Balanced	Moderate	Demand is unpredictable or seasonal

OM Capacity planning problems

Ex-3.1 A product line manufacturing shoes has five stations in series whose individual capacities per shift are stated in the following table. The actual o/p of the line is 500 pairs per shift.

Find: (a) The system capacity

(b) The system efficiency

Station No.	1	2	3	4	5
Individual capacity / shift	600	650	650	550	600

Soln

In a series line, the system capacity is determined by the bottleneck station (the station with the smallest individual capacity)

System capacity = min (600, 650, 650, 550, 600)

= 550 pairs / shift

(limited by station 4)

System efficiency compares the actual output to the system capacity.

$$\text{System efficiency}(\%) = \frac{\text{Actual output}}{\text{System capacity}} \times 100$$

$$= \frac{500}{550} \times 100 = 90.91\%$$

Ex-3.2 An automobile component manufacturer has the plan of buying a moulding m/c which can manufacture 170,000 good parts per year. The moulding m/c is a part of a product line. The System efficiency of the product line is 85%.

(a) What is the reqr systems capacity?

(b) Assume that it takes 100 seconds to mould each part & the plant operates 2000 hrs per year. If the moulding m/cs are used only 60% of the time and are 90% efficient, what is the actual o/p of the moulding m/c per hour?

(c) How many moulding m/cs would be reqr?

Reqr good parts per year = 170,000

System efficiency = 85% = 0.85

Capacity needed

$$C = \frac{\text{Reqr output}}{\text{System efficiency}}$$

$$\left(\because \text{System efficiency} = \frac{\text{Actual O/P}}{\text{System Capacity}} \right)$$

C (System capacity) = $\frac{170,000}{0.85}$

= 200,000 parts / year.

(b) Actual Output of the moulding-machine per hour

Given: Time to mould one part = 100 seconds.

m/c is used only 60% of the time.

m/c efficiency = 90%.

1 hour = 60 min = 3600 seconds

Theoritical prodn per hour

parts per hour =

In 100 seconds → 1 part produced

In 3600 seconds → $\frac{1}{100} \times 3600$ = 36 parts produced

↓

ie

In 1 hour → 36 parts produced.

OM

~~O/P per year = Unit capacity x~~

Output per hour

$= \text{Unit capacity} \times \% \text{ Utilization} \times \text{Efficiency}$

$= 36 \times 0.6 \times 0.9$

$= 19.44$ moulds

$= 20$ moulds approx

(C) How many moulding m/c would be required?

Number of moulding m/c needed

$$= \frac{\text{System capacity}}{\text{output per hour}}$$

$$= \frac{100}{20} = 5 \text{ m/c reqr.}$$

PLANT LAYOUT TYPES: PRODUCT, PROCESS, CELLULAR, FIXED POSITION

Plant layout is a floor plan of the physical facilities which are used in production.

Plant layout is the *physical arrangement* of machines, workstations, storage areas, utilities and people in a factory or service facility so that material, information and people flow smoothly and efficiently from start to finish of a process. A good layout reduces cost, improves productivity, and improves safety and working conditions.

Hence layout planning refers to the generation of several possible plans for the spatial arrangement of physical facilities and select one which minimized the distance between the departments.

Why plant layout matters

- Reduces material handling & transit time, which lowers cost and damage.

- Improves workflow and throughput (faster production).
- Raises equipment and labour utilization.
- Improves safety, ergonomics and morale.
- Makes supervision, control and maintenance easier.
- Supports flexibility and future expansion.

Main objectives

1. Minimize total material handling cost and movement.
2. Ensure smooth, uninterrupted workflow i.e. facilitate the manufacturing process and organizational structure.
3. Minimize work-in-process inventory and production lead time.
4. Maximise utilization of space, equipment and labour.
5. Ensure safety, comfort and ease of supervision.

6. Provide flexibility for changes in product mix, capacity and technology.

Fundamental design principles

- **Flow continuity**: Layout should match product/process flow with minimal backtracking.
- **Minimise material movement**: Shortest, simplest routes between operations.
- **Use space efficiently**: Vertical and horizontal space both.
- **Flexibility/modularity**: Able to handle product changes and expansion.
- **Accessibility & visibility**: Easy access for maintenance, inspection and supervision.
- **Safety & ergonomics**: Adequate clearance, lighting, safe aisles.
- **Balance**: Balance workloads and avoid bottlenecks.
- **Standardization**: Use standard workstations and fixtures where possible.

TYPES OF PLANT LAYOUT

1. Process layout or Functional layout (similar processes grouped together (departments by function)).

Definition: Machines of similar type are grouped together to perform similar operations. In a process layout, similar machines and services are located together. Therefore, all drills will be located in one area of the plant. Process layout is normally used when the production volume is not sufficient to justify a product layout. Typically, job shops employ process layouts due to the variety of products manufactured and their low production volumes.

Used when: Production is **intermittent or job-type** (variety of products, small quantity).

Example: Machine shops, hospitals, custom furniture manufacturing.

Advantages:

- Machines are better utilized; fewer machines are required.
- A high degree of flexibility in terms of task allocation to machines exists.
- Comparatively low investment in machines is required.
- The diversity of tasks offers a more interesting and satisfying occupation for the operator.

Disadvantages:

- Material handling cost will be high.
- Production planning and control systems are more involved.
- Throughput time is longer.
- Large amounts of in-process inventory will result.
- Space and capital are tied up by work in process.
- Higher grades of skill are required.

2. Product Layout or Line Layout (equipment arranged in sequence of operations)

Definition: Machines and equipment are arranged **in the sequence of operations** required to manufacture a product. Product layout is used when machines and auxiliary services are located according to the processing sequence of the product. The product layout is selected when the volume of production of a product is high such that a separate production line to manufacture it can be justified. In a strict product layout, machines are not shared by different products. Therefore, the production volume must be sufficient to achieve satisfactory utilization of the equipment.

Used when: Production is **continuous or mass** (large volumes of standardized products) and low variety products

Example: Automobile assembly line, bottling plant.

Advantages:

- The flow of product will be smooth and logical in flow lines.
- In-process inventory is less.
- Throughput time is less.
- Material handling cost is minimum.
- Operators need not be skilled.
- Simple production planning and control systems are possible.
- Less space is occupied by work in transit and for temporary storage.

Disadvantages:

- A Breakdown of one machine in a product line may cause stoppages of machines in the downstream of the line.
- A change in product design may require major alterations in the layout.

    - The line output is decided by the bottle neck machine.
    - Comparatively high investment in equipments is required.

3. Cellular layout or Group-technology Layout (machines grouped into cells to process a family of similar parts)

Definition: Machines are grouped into **cells**, each dedicated to processing a family of parts with similar characteristics. A group layout is a combination of the product layout and process layout. It combines the advantages of both layout systems. If there are m machines and n components, in a group technology layout, the m-machines and n-components will be divided into distinct number of machine-components cells (groups) such that all the components assigned to a cell are almost processed within that cell itself. Here the objective is to minimize the intercell movements. The basic aim of a group technology layout is to identify families of components that require similar processing on a set of machines. In turn, these machines are grouped into cells. Each cell is capable of satisfying all the requirements of the component family assigned to it.

Used when: Production is **medium volume and medium variety**.

Example: Electronic component manufacturing/ assembly, CNC machine cells.

Advantages:

- Group technology layout can increase the items given in List A and it can decrease the items given in List B.
- List A: Component standardization and rationalization. Reliability of estimates. Effective machine operation. Productivity. Costing accuracy. Customer service. Order Potential.
- Lis B: Planning effort. Paper work. Setting time. Down time. Work in progress. Work Movement. Overall Production times. Finished part stock. Overall cost

- Combines flexibility of process layout and efficiency of product layout.
- Reduced material handling and setup time.
- Improved quality and teamwork.

Disadvantages:

- Costly initial setup.
- Requires detailed part family analysis.
- This type of layout may not be feasible for all situations. If the product mix is completely dissimilar then we may not have meaningful cell information.

4. Fixed-position layout or Project Layout (product stays in place; resources brought to it)

Definition: The **product remains stationary**, and workers, materials, and equipment are brought to it. This fourth type of layout is the static product layout, or layout by fixed position, in which the physical characteristics of the product dictate as to which type of machines and men are to be brought to the product. The ship building industry commonly employs a static product layout. Since, the static product layout is not justified except in unusual situations, it has limited scope.

Used when: Product is **large, bulky, or heavy** and cannot be easily moved (immobile products).

Example: Shipbuilding, aircraft assembly, construction sites.

Advantages:

- Minimal material movement.
- Suitable for large projects.
- High product customization.

Disadvantages:

- Low equipment utilization.
- Difficult supervision and coordination.
- High material handling cost (to bring tools and parts to the site).

The layout design process considers mostly a single objective while designing layouts. In process layout, the objective is to minimize the total cost of material handling. Because of the nature of the layout, the cost of equipments will be minimum in this type of layout. In product layout the cost of materials handling will be at the absolute minimum. But the cost of equipments would not be at the minimum if the equipments are not fully utilized. In group technology layout, the objective is to minimize the sum of the cost of transportation and the cost of equipments. So this is called as multi-objective layout.

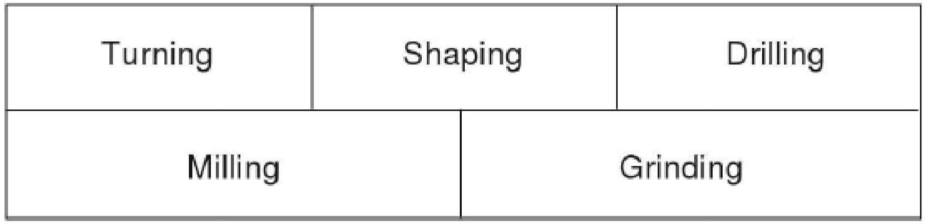


Fig. 6.1 Process layout.

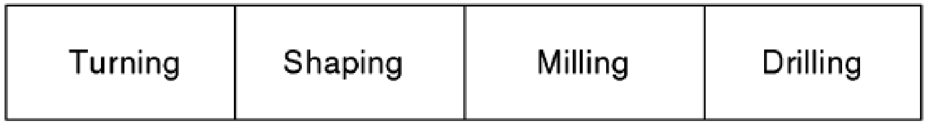


Fig. 6.2 Product layout.

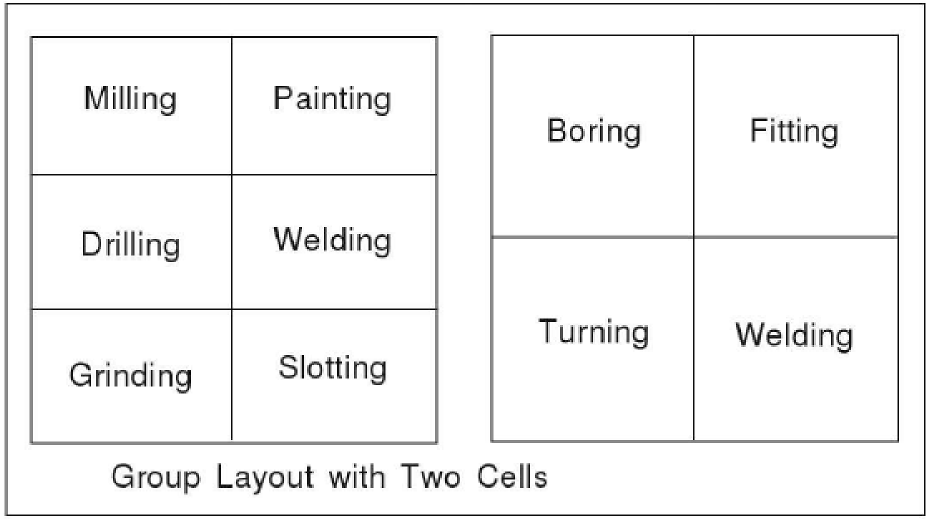


Fig. 6.3 Group layout.

Factors to consider when designing a layout

- Types of products and production volume.
- Process flow and operation sequence.
- Material handling methods (conveyors, forklifts, AGVs).
- Space availability and building constraints.
- Safety, environmental and regulatory requirements.
- Worker requirements, human factors and ergonomics.
- Machine characteristics (size, utility needs, noise).
- Future expansion and product mix flexibility.
- Cost constraints (capital and operating).
- Maintenance, cleaning and waste disposal needs.

Steps in plant layout planning (practical workflow)

1. **Define objectives & constraints** (capacity, budget, safety).
2. **Collect data**: process sequences, equipment sizes, material flows, volumes, frequencies.
3. **Analyse flows**: prepare flow process charts and material flow matrices.
4. **Develop alternatives**: sketch block layouts and then detailed layouts.
5. **Evaluate alternatives** using criteria (material handling cost, throughput, safety).
6. **Select best layout** and create detailed drawings (floor plan, utilities, clearances).
7. **Implement** (move equipment, set up workstations, train staff).
8. **Monitor & improve** (measure KPIs and refine).

Tools & techniques used

- **Flow process charts** (operation, transportation, inspection symbols).
- **Material flow analysis / flow matrix** (quantifies movement between departments).

- **Relationship chart (REL chart)** — qualitative closeness ratings (A, E, I, O, U, X).
- **String diagram / spaghetti diagram** — traces actual movement to spot inefficiencies.
- **Block layout & detailed layout drawings**.
- **Line balancing** (for product layout) to balance work across stations.
- **Systematic Layout Planning (SLP)** — structured approach: data → activity relationships → space requirements → layout alternatives → evaluation.
- **Computer simulation / discrete-event simulation** — test throughput, bottlenecks and variability.
- **Heuristic/optimization algorithms** (e.g., CRAFT — Computerized Relative Allocation of Facilities Technique) for facility arrangement.

LAYOUT DESIGN PROCEDURES

Layout design procedure can be classified into manual methods and computerized methods.

Manual Methods: Under this category, there are some conventional methods like travel chart and systematic layout Planning (SLP).

Computerized Methods: Under this method, again the layout design procedure can be classified into constructive type algorithms and improvement type algorithms.

Construction type algorithms

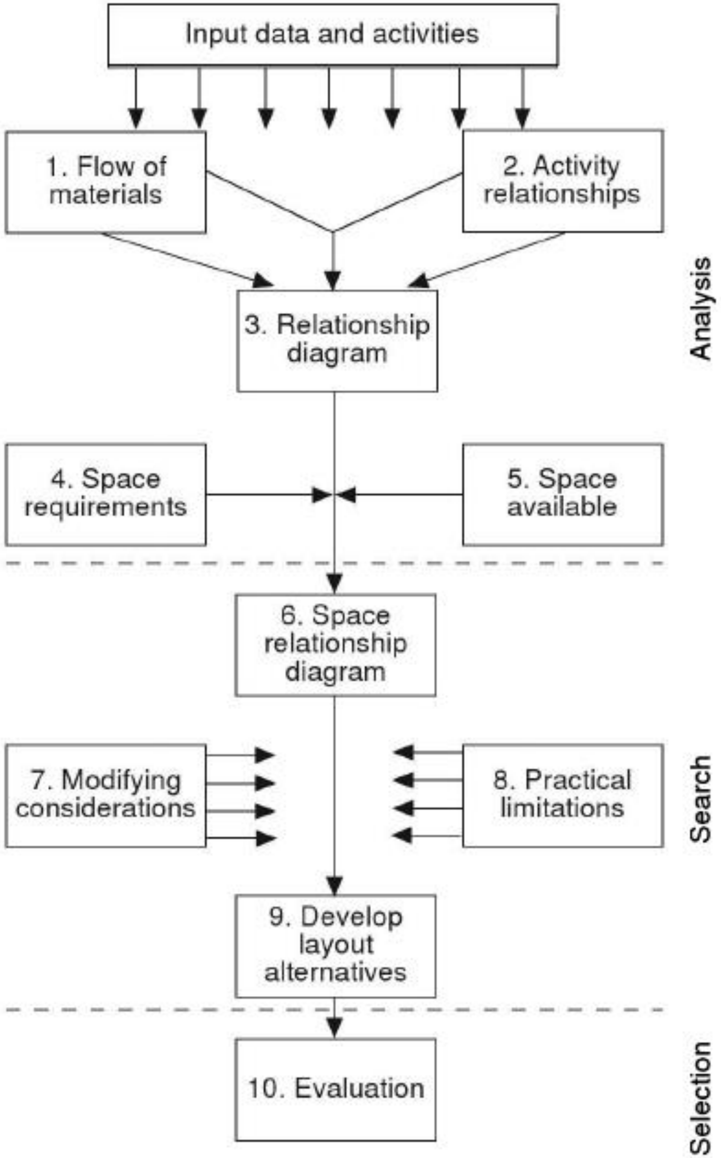
- Automated Layout Design Program (ALDEP)
- Computerized Relationship Layout Planning (CORELAP)

Improvement type algorithms

- Computerized Relative Allocation of Facilities Technique (CRAFT)

SYSTEMATIC LAYOUT DESIGN PROCEDURE

An organized approach to layout planning has been developed by Muther and has received considerable publicity due to the success derived from its application in solving a large variety of layout problems. This approach is referred to as systematic layout planning or simply SLP. This procedure is shown in figure below. From the figure, it is clear that once the appropriate information is gathered, a flow analysis can be combined with an activity analysis to develop the relationship diagram. The space-relationship diagram is constructed by combining space considerations with the relationship diagram. Based on the space-relationship diagram, modifying considerations and practical limitations, a number of alternative layouts are designed and evaluated. In comparison with the steps in the design process, SLP begins after the problem is formulated.



Systematic Layout Planning Procedure

COMPUTERIZED RELATIVE ALLOCATION OF FACILTIES TECHNIQUES (CRAFT)

CRAFT algorithm was originally developed by Armour and Buffa. CRAFT is more widely used than ALDEP and CORELAP. It is an improvement algorithm. It starts with an initial layout and improves the layout by interchanging the departments pairwise so that the transportation cost is minimized. The algorithm continues until no further interchanges are possible to reduce the transportation cost. The result given by CRAFT is not optimum in terms of minimum cost of transportation. But the result will be good and close to optimum in majority of applications. Hence, CRAFT is mainly a heuristic algorithm. Unfortunately, plant layout problem comes under combinatorial category. So, usage of efficient heuristic like CRAFT is inevitable for such problem.

CRAFT requirements

1. Initial layout
2. Flow data
3. Cost per unit distance
4. Total number of departments
5. Fixed departments

   Number of such departements

   Location of those departments

6. Area of departments.

CRAFT Procedure

The steps of CRAFTS algorithm are summarized below:

Step 1.

Input 1. Number of departments.

Input 2. Number of interchangeable departments.

Input 3. Initial layout.

Input 4. Cost matrix

Input 5. Flow matrix

Input 6. Area of departments

Step 2. Compute centroids of departments in the present layout.

Step 3. Form distance matrix using the centroids.

Step 4. Given date on flow, distance and cost, compute the total handling cost of the present layout.

Step 5. Find all the possible pairwise interchanges of departments based on common border or equal area criterion. For each possibilty, interchange the corresponding centroids and compute approximate costs.

Step 6. Find the pair of departments corresponding to the miniumum handling cost from among all the possible pairs of interchanges.

Step 7. Is the cost in the previous step less than the total cost of the present layout? If yes, go to Step 8. If not, go to Step 11.

Step 8. Interchange the selected pair of departments. Call this as the NEW LAYOUT. Compute centroids, distance matrix and total cost.

Step 9. Is the cost of new layout less than the cost of the present layout?

If yes, go to Step 10. If not, go to Step 11.

Step 10. The new layout is here after considered as the PRESENT LAYOUT. Its data on centroids, layout matrix and the total cost is retained. Go to Step 5.

Step 11. Print the present layout as the FINAL LAYOUT.

Step 12. Stop.

Performance measures (what to track)

- **Material handling cost** (₹ or $ per unit).
- **Throughput / output per time**.
- **Work-in-progress (WIP)** inventory level.
- **Cycle time / lead time**.
- **Machine and labour utilisation (%)**.
- **Number of touches per unit** (lower is better).
- **Shipping accuracy / defect rates** (quality impacts layout indirectly).
- **Space utilisation (m^2 used vs available)**.

Advantages & disadvantages (general)

Advantages

- Lower operating cost, faster production, improved safety, better supervision, higher capacity utilisation.

Disadvantages

- Initial redesign/rearrangement cost, possible downtime during changeover, sometimes less flexibility (esp. product layouts).

Special considerations

- **Service layouts** (banks, hospitals, restaurants) emphasize customer flow, waiting area design, privacy and ergonomics. Often blend process and fixed layouts.

- **Lean & cellular layouts** aim to reduce waste (transport, inventory) and often use U-shaped cells for flexibility and worker interaction.
- **Sustainability**: plan for waste handling, energy efficiency, daylighting and material recycling.
- **Automation**: conveyors, AGVs and robots change space and utility needs — must be planned early

Practical checklist before finalizing a layout

- Have you mapped actual material flows and peak loads?
- Are clearances, maintenance access and safety routes included?
- Is utility routing (power, compressed air, water) feasible?
- Have you planned for future expansion and changes in product mix?
- Have staff, supervisors and maintenance given input?
- Is there a contingency plan for machine breakdowns?

- Has a small-scale simulation or pilot test been run?

Example (toy problem)

Imagine a small metal shop with three operations: cutting → drilling → finishing. Demand is moderate and product families are similar. Options:

- **Process layout**: group all cutting machines together, all drills together → flexible but more movement between departments.
- **Cellular layout**: create one cell with one cutting, one drilling, one finishing machine dedicated to that family → reduces movement, faster throughput, easier supervision.

Production Planning and Control (PPC): functions, phases (pre-planning, planning, control).

Production Planning and Control (PPC) is an essential function in **manufacturing and operations management** that ensures the **right quantity of products** is produced **at the right time**, using **the right resources**, and **at minimum cost**.

It integrates **planning**, **routing**, **scheduling**, **dispatching**, and **follow-up** activities to achieve smooth and efficient production flow.

It involves determining *what to produce, when to produce, how much to produce,* and *how to ensure that the production plan is executed effectively.*

According to **Buffa**, *"Production control is the process of planning and regulating the operations of that part of an enterprise which is responsible for the actual transformation of materials into finished products."*

Objectives of Production Planning and Control

- Ensure **smooth and uninterrupted production flow**.
- **Optimize resource utilization** (man, machine, and materials).
- Maintain **optimum inventory levels**.
- Meet **delivery schedules** on time.
- Achieve **cost efficiency** and **quality assurance**.
- Coordinate different departments (design, purchase, production, dispatch).

Functions of Production Planning and Control

Main Function	Description
1. Planning	Deciding in advance what, when, and how production should be carried out.
2. Routing	Determining the exact **path or sequence of operations** for each product or component.
3. Scheduling	Establishing the **start and finish times** for each operation or job.
4. Loading	Assigning specific **jobs to machines or work centers** based on capacity.
5. Dispatching	Giving **authorization to start work** as per the schedule — includes issuing materials and instructions.

6. Follow-up / Expediting	Monitoring progress of work and removing bottlenecks to maintain workflow.
7. Inspection	Ensuring **quality standards** are met in every stage of production.
8. Corrective Action	Taking remedial steps to **eliminate deviations** and improve performance.

Phases of Production Planning and Control

PPC operates in **three main phases** — each with distinct roles and responsibilities:

A. Pre-Planning Phase

This is the **preparatory stage** — before actual production planning begins.

Main Activities:

1. **Product Design and Development:**
    - Determine specifications, drawings, and standards.
2. **Process Design:**
    - Decide manufacturing methods, equipment, and tools.
3. **Forecasting Demand:**
    - Estimate customer demand using past data and market trends.
4. **Capacity Planning:**
    - Evaluate available resources (manpower, machines, materials).
5. **Facilities Planning:**
    - Ensure layout, workspace, and utilities are sufficient for production.

Output: Clear idea of what can be produced and available capacity.

B. Planning Phase

This is the **core stage** of PPC — where actual plans are formulated for smooth production.

Main Activities:

1. **Routing:**
   - Identify the best route and sequence of operations.
2. **Loading:**
   - Allocate specific jobs to machines or work centers.
3. **Scheduling:**

    - Fix timing for operations (start and completion dates).

4. **Dispatching:**
    - Authorize production to start as per the schedule.

Output: A detailed production plan and timetable.

C. Control Phase

This phase ensures that **production follows the plan** and corrective actions are taken for deviations.

Main Activities:

1. **Progress Reporting & Follow-up:**
    - Monitor actual performance vs planned schedule.

2. **Inspection and Quality Control:**
    - Check whether standards and tolerances are maintained.
3. **Corrective Actions:**
    - Reschedule jobs, adjust resources, or remove bottlenecks if needed.

Output: Controlled, efficient, and quality-oriented production process.

Elements of PPC

- Design and Routing of processes.
- Forecasting and capacity planning.
- Inventory and material control.
- Scheduling and sequencing.
- Monitoring and feedback systems.

Importance of PPC

- Increases **production efficiency**.
- Reduces **idle time** of machines and workers.
- Helps in **timely delivery** of products.
- Minimizes **wastage of resources**.
- Improves **coordination** between departments.
- Enhances **customer satisfaction** and **profitability**.

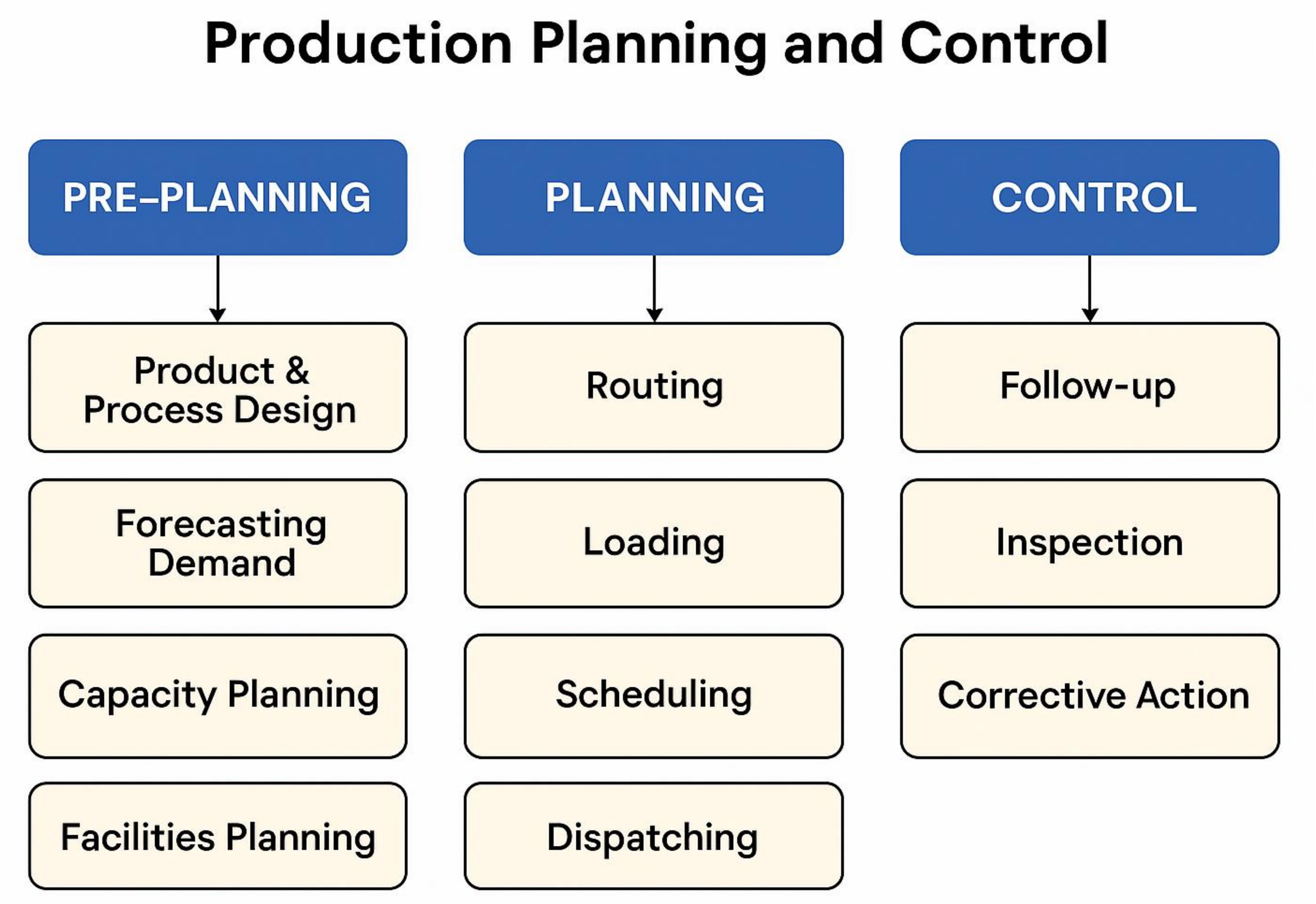
Limitations of PPC

- Requires **accurate data** and continuous monitoring.
- Difficult to manage in **small-scale industries**.
- Complex in **multi-product or job-order systems**.

- Dependent on **external factors** like supplier delays or machine breakdowns.

Conclusion

Production Planning and Control (PPC) acts as the **nervous system** of the manufacturing process. It ensures that resources are utilized efficiently, operations are well-coordinated, and production targets are achieved on time with minimum cost and maximum quality.


Production Planning and Control
PRE-PLANNING
Product & Process Design
Forecasting Demand
Capacity Planning
Facilities Planning
PLANNING
Routing
Loading
Scheduling
Dispatching
CONTROL
Follow-up
Inspection
Corrective Action

Introduction

Aggregate Planning (AP) is a **medium-term production planning process** that determines the **optimal production, inventory, and workforce levels** over a specific period (usually 3 to 18 months).

The goal is to balance **supply and demand** in the most cost-effective way while meeting organizational objectives.

Aggregate Production Planning (APP) is a **medium-term production planning process** that determines the **optimal quantity and timing** of production to meet fluctuating demand while minimizing costs. It bridges the gap between **long-term strategic planning** and **short-term scheduling**.

Time Horizon: Usually 3 to 18 months

Objective: To balance demand and production capacity efficiently.

Definition

According to **APICS**,

“Aggregate planning is the process of developing, analyzing, and maintaining a preliminary, approximate schedule of the overall operations of an organization.”

It translates the company’s **long-term strategic plans** into **short-term operational plans**.

Objectives of Aggregate Production Planning

Objective	Description
1. Balance Demand and Capacity	Match production rates, workforce, and inventory with customer demand.
2. Minimize Production Cost	Reduce total cost, including labour, inventory, and subcontracting.
3. Maintain Workforce Stability	Avoid frequent hiring and layoffs by planning manpower needs efficiently.
4. Optimize Inventory Levels	Keep sufficient inventory to meet demand without overstocking.

5. Ensure Smooth Production Flow	Avoid bottlenecks and maintain steady operations.
6. Improve Customer Service	Meet delivery schedules and maintain quality.
7. Utilize Resources Efficiently	Maximize use of plant, equipment, and manpower.

Main objectives of Aggregate Planning

- To **meet customer demand** on time.
- To **minimize total production cost** (including labor, inventory, and hiring/firing).
- To **utilize resources efficiently**.
- To **stabilize employment** and production rates.
- To **plan for changes in demand** and manage capacity accordingly.

Inputs to Aggregate Planning

1. **Demand Forecasts:** Predicted customer demand over the planning horizon.
2. **Capacity Constraints:** Available manpower, machines, and materials.
3. **Inventory Levels:** Stock on hand and storage capacity.
4. **Workforce Data:** Hiring, firing, and training capabilities.

5. **Cost Information:** Costs of labor, production, inventory holding, and shortages.
6. **Organizational Policies:** Overtime limits, subcontracting rules, etc.

Outputs of Aggregate Planning

- **Production schedule** for each period.
- **Inventory levels** to be maintained.
- **Workforce plan** (hiring, layoffs, overtime).
- **Subcontracting decisions.**

Strategies for Aggregate Planning

A. Demand (Output) Options:

Used to influence or manage customer demand.

1. **Promotion and advertising.**
2. **Pricing adjustments.**
3. **Backordering** (delaying delivery).
4. **Demand shifting** to off-peak periods.

B. Supply (Capacity) Options:

Used to adjust production capacity.

1. **Hiring and layoffs.**
2. **Overtime or idle time.**
3. **Subcontracting.**
4. **Part-time or temporary workers.**
5. **Inventory buildup** during low demand.

C. Mixed Strategy:

Combination of both demand and capacity options for flexibility and cost balance.

Strategy	Description	Advantages	Disadvantages
Chase Strategy	Match production rate to demand by hiring/firing workers.	Low inventory cost.	High hiring/firing cost; worker morale issues.
Level Strategy	Maintain constant production rate and workforce; use inventory or backorders to absorb demand fluctuations.	Stable workforce; predictable output.	High inventory or backorder costs.

Strategy	Description	Advantages	Disadvantages
Hybrid Strategy	Combine both to achieve a cost-effective balance.	Flexible; moderate cost.	Complex to plan and control.

Methods / Techniques of Aggregate Planning

1. **Graphical and Charting Methods:** Simple trial-and-error visual approach.
2. **Mathematical / Optimization Techniques:**
   - **Linear Programming (LP)**
   - **Transportation Model**
   - **Simulation Models**
   - **Heuristic Methods**

Planning Horizon

Aggregate planning typically covers **3 to 18 months**—the time required to adjust production levels, workforce size, and inventory without drastic changes.

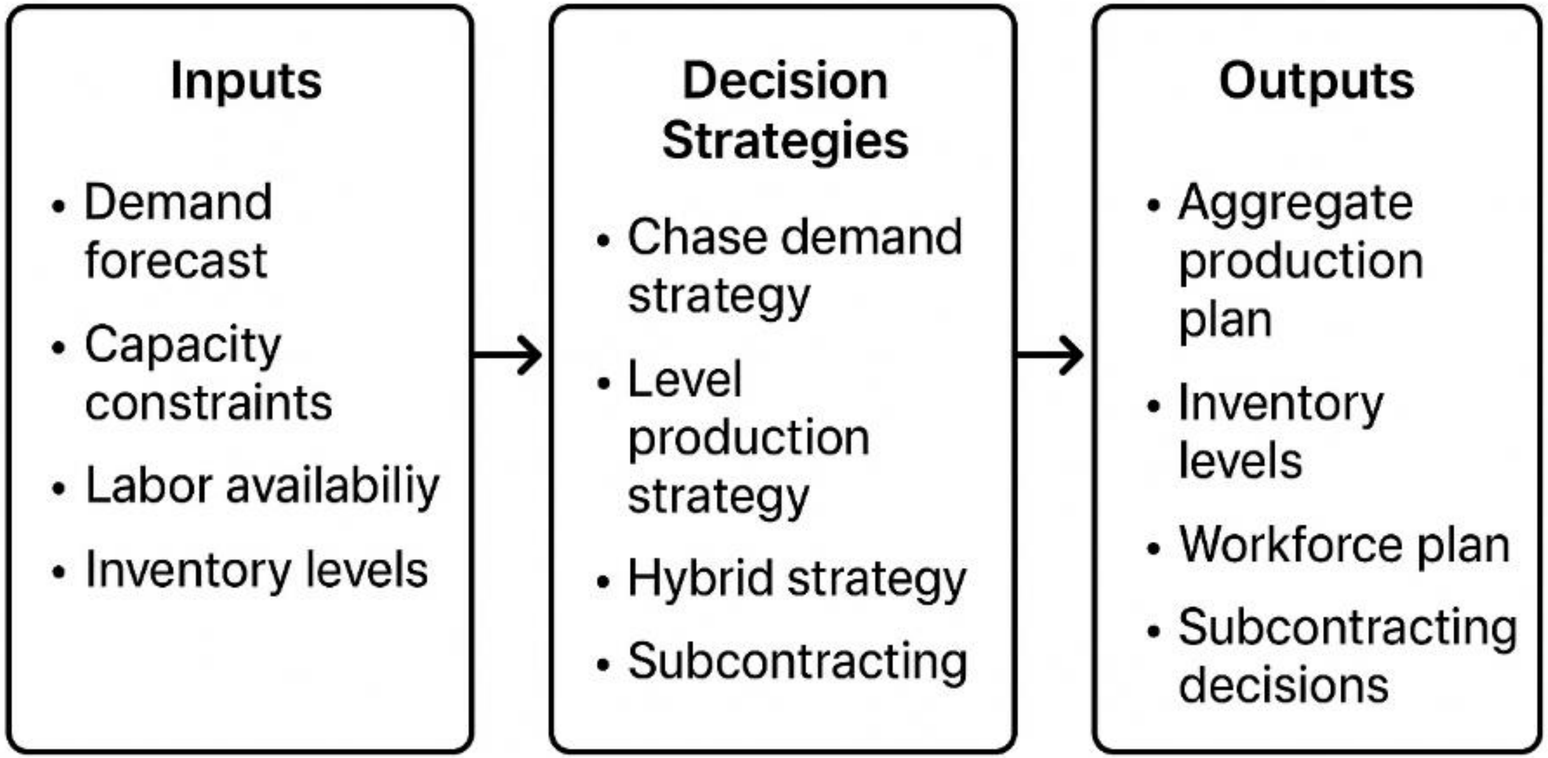
Benefits of Aggregate Planning

- Minimizes cost of operations.
- Ensures timely fulfilment of demand.
- Reduces overproduction and stockouts.
- Balances workforce levels.
- Improves resource utilization and efficiency.

Limitations

- Based on **forecast accuracy** — any error affects planning.
- May not handle sudden market changes.
- Requires **coordination across departments** (marketing, HR, production).
- Complex when dealing with multiple products or uncertain demand.

AGGREGATE PLANNING PROCESS



Inputs

- Demand forecast
- Capacity constraints
- Labor availabiliy
- Inventory levels

Decision Strategies

- Chase demand strategy
- Level production strategy
- Hybrid strategy
- Subcontracting

Outputs

- Aggregate production plan
- Inventory levels
- Workforce plan
- Subcontracting decisions

Conclusion

Aggregate Planning serves as a **bridge between long-term strategic planning and short-term scheduling**.
It aligns resources and production levels with market demand in the most economical way, ensuring stability and efficiency in operations.

Basis of Comparison	Aggregate Planning (AP)	Material Requirement Planning (MRP)
1. Meaning	It is a **medium-term planning process** that determines **overall production, inventory, and**	It is a **detailed planning system** that determines **what materials are required, in what quantity, and when** to produce a product.

	workforce levels to meet demand.	
2. Focus	Focuses on **aggregate (overall) output levels** and **capacity**.	Focuses on **detailed component-level planning** for materials and parts.
3. Planning Level	**Macro-level** planning (total production and resources).	**Micro-level** planning (individual items and components).
4. Time Horizon	Medium-term (3 to 18 months).	Short-term (daily to weekly planning).
5. Inputs Required	- Demand forecast	

6. **Output** | Aggregate production plan, inventory levels, workforce plan, subcontracting decisions. | Material order schedules, planned order releases, and purchase orders. |

   | **7. Objective** | To **balance demand and supply** at the lowest possible cost while maintaining stable operations. | To **ensure materials are available** for production and final products are available for delivery. |

   | **8. Nature of Demand** | Deals with **independent demand** (for finished goods). | Deals with **dependent demand** (for components and subassemblies). |

   | **9. Decision Variables** | Total production rate, workforce size, inventory level, overtime, and subcontracting. | Order quantity, timing of orders, inventory replenishment schedules. |

   | **10. Tools/Techniques Used** | Graphical methods, Linear programming, Heuristics. | Computer-based MRP software systems. |

| **11. Relationship** | Provides the **overall production plan**. | Uses the **master production schedule (derived from aggregate plan)** to plan materials. |

| **12. Goal** | To create a feasible and cost-effective **aggregate production plan**. | To create a detailed and time-phased **material requirement schedule**. |

In Summary

- **Aggregate Planning** = *“How much to produce and when.”*
- **MRP** = *“What materials are needed and when.”*

Explanation:

- **Aggregate Planning** determines *overall production levels* and *capacity*.
- **MPS** converts the aggregate plan into *specific product schedules*.
- **MRP** breaks down those schedules into *detailed material and component requirements*

Master Production Schedule (MPS)

Introduction

The Master Production Schedule (MPS) is a central planning document in production management that specifies what end items are to be produced, in what quantities, and at what time.
It converts the Aggregate Production Plan (APP) into specific, time-phased production schedules for individual products.

MPS acts as a link between strategic planning and operational execution, and serves as a key input to Material Requirement Planning (MRP) and capacity planning.

Definition

According to **APICS**:

“The Master Production Schedule is a statement of what the company expects to manufacture, expressed in specific configurations, quantities, and dates.”

Objectives of Master Production Schedule

The main objectives of MPS are:

1. To **meet customer demand** and delivery commitments
2. To **translate aggregate plans into detailed schedules**
3. To provide a **basis for material requirement planning (MRP)**
4. To ensure **efficient utilization of production capacity**

5. To minimize **inventory holding and stock-out costs**

6. To coordinate activities of **production, marketing, and procurement**

Position of MPS in Production Planning Hierarchy

Long-term planning → Aggregate Production Planning (APP)

⬇

Medium-term planning → Master Production Schedule (MPS)

⬇

Short-term planning → MRP, shop-floor scheduling, dispatching

Thus, MPS bridges **aggregate planning** and **detailed material planning**.

Inputs to Master Production Schedule

The accuracy and effectiveness of MPS depend on reliable inputs:

1. **Aggregate Production Plan** – overall production targets
2. **Demand Forecasts** – expected future demand
3. **Customer Orders** – confirmed and priority orders
4. **Inventory Status** – available finished goods stock
5. **Production Capacity** – machine and labor availability
6. **Lead Times** – manufacturing and procurement lead times
7. **Company Policies** – lot sizes, safety stock, service level

Outputs of Master Production Schedule

MPS generates the following outputs:

1. **Time-phased production quantities** for each end product
2. **Delivery schedules and commitments**
3. **Input to MRP system** for material planning
4. **Input to capacity planning (RCCP & CRP)**
5. **Management control information**

Time Fences in MPS

Time fences divide the planning horizon into zones with different levels of flexibility.

Time Fence	Description
Frozen Zone	Schedule cannot be changed; materials and capacity already committed

Slushy Zone	Limited changes allowed with management approval
Liquid Zone	Schedule can be changed freely

Time fences help maintain **schedule stability** while allowing flexibility.

Types of Demand in MPS

1. **Independent Demand** – demand for finished products
2. **Dependent Demand** – demand for components (handled by MRP)

MPS deals **only with independent demand**.

MPS and Capacity Planning

Before finalizing MPS, a **feasibility check** is essential:

Rough-Cut Capacity Planning (RCCP)

- Verifies whether **key resources** (labor, machines) can support the MPS
- Prevents overloading or underutilization of capacity

If capacity is insufficient, MPS must be revised by:

- Changing production quantities
- Using overtime or subcontracting
- Revising delivery dates

MPS and Available-to-Promise (ATP)

Available-to-Promise (ATP) indicates how much inventory is available for new customer orders.

ATP = Projected Available Balance- Customer Orders

ATP improves **customer service and order commitment accuracy**.

Benefits of Master Production Schedule

- Improves **production planning accuracy**
- Enhances **customer satisfaction**
- Reduces inventory and production costs
- Improves coordination between departments
- Provides a realistic input for **MRP and capacity planning**

Limitations of MPS

- Highly dependent on **forecast accuracy**
- Requires continuous updating and monitoring
- Difficult to manage in highly uncertain environments
- Ineffective without accurate inventory and BOM data

Example

If a company plans to produce **500 units of Product A** in Week 4, this quantity and timing are specified in the MPS.

MRP then determines **how many components and raw materials** are needed and when.

Conclusion

The **Master Production Schedule** is the **heart of production planning**.

It ensures that production activities are **customer-oriented, capacity-feasible, and cost-effective**, while providing a strong foundation for **material planning and shop-floor control**.

OM

①

LPP (Linear programming)

Simple optimization process.

All variables are linear.

Constraints are linear within the limit.

→ 2 methods solve

>> Graphical method

>> Simplex method (Analytical method)

Linear programming is a mathematical method used to optimize a linear objective function, subject to a set of linear equality & inequality constraints.

Its widely applied in operations research, economics, engineering, & various other fields where optimal decision making is crucial.

Especially, LP involves maximizing or minimizing a linear function (like profit or cost) while satisfying certain linear constraints (like resource limitations or production capacities)

OM

~~Ia graphical method~~

Methods used to solve Linear programming problems (LPP) mainly depend on the number of variables and constraints involved. Here are the main methods of solving LPP.

(1) Graphical method

Suitable for problems with two decision variables.

It involves plotting constraints & objective function on a graph to find the optimal soln at the intersection of constraints.

(2) Simplex method

Most common method for solving LP problems.

Its iterative and involves moving from one feasible soln to another to improve the objective fn value untill the optimal soln is found.

(3) Dual simplex method

This variant of the simplex method is used when the primal problem is infeasible or unbounded. It focuses on the dual problem to determine feasibility or find an optimal soln.

(4) Interior point. (Barrier method)

Unlike the simplex method, this method Stays within the feasible region throughout the process. It uses the Concepts of barriers to Gradualy approach the optimal soln.

(5) Big M Method

This method Converts inequality constraints into equations using a Large penalty parameter M. Its used when some variables are reqr to be zero at the optimal soln.

It ensures artificial variables are removed in the final soln.

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Graphical method

Having (i) Objective function

(ii) Constraint / Restrictions / Conditions.

Using constraints either we do maximise or minimise the objective fn.

ex ÷ Cost minimise

prodn maximise.

advn ÷ problem optimize

quality of decision

Linear variable

Disadvn ÷

(i) Limited to two variables

(ii) Difficult with many constraints

(iii) Accuracy issue

(iv) No use in Large scale problems.

Steps of graphical method

(i) Formulate the problem (LPP)

(ii) Draw the graph including all constraints.

(iii) Find the feasible region & check the corner points.

(iv) Choose the optimal soln.

LPP formulation ⇒

wood almirah, table.
chair

Let 4 products we are manufacturing →
for that we need P, Q, R item.

wood — P

fevicol ← Q

Paint ~~glue~~ — R

	A (x_1)	B (x_2)	C (x_3)	D (x_4)	Resource available
P	5	4	3	6	150 kg
Q	2	3	2	4	80 kg
R	3	2	4	5	100 litre
Profit (₹) per unit	50	120	80	50	

Technological coefficient

Profit co-efficient

Resource value

$x_1, x_2, x_3, x_4 \Rightarrow$ Decision variable

Objective f^n $\Rightarrow$

$$Z = 50x_1 + 120x_2 + 80x_3 + 150x_4$$

Constraints

$$\begin{cases} 5x_1 + 4x_2 + 3x_3 + 6x_4 \leq 150 \\ 2x_1 + 3x_2 + 2x_3 + 4x_4 \leq 80 \\ 3x_1 + 2x_2 + 4x_3 + 5x_4 \leq 100 \end{cases}$$

$$x_1, x_2, x_3, x_4 \geq 0$$

In general form if we want to write the objective f^n :

Objective f^n:

$$c_1x_1 + c_2x_2 + \ldots\ldots + c_nx_n$$

Constraint:

Constraint or condition

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + \ldots\ldots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{21}x_2 + \ldots\ldots + a_{2n}x_n \leq b_2 \\ \vdots \\ a_{m1}x_1 + a_{m}x_2 + \ldots\ldots + a_{m}x_n \leq b_n \end{cases}$$

$i = 1 \ldots\ldots n$

$j = 1 \ldots\ldots m$

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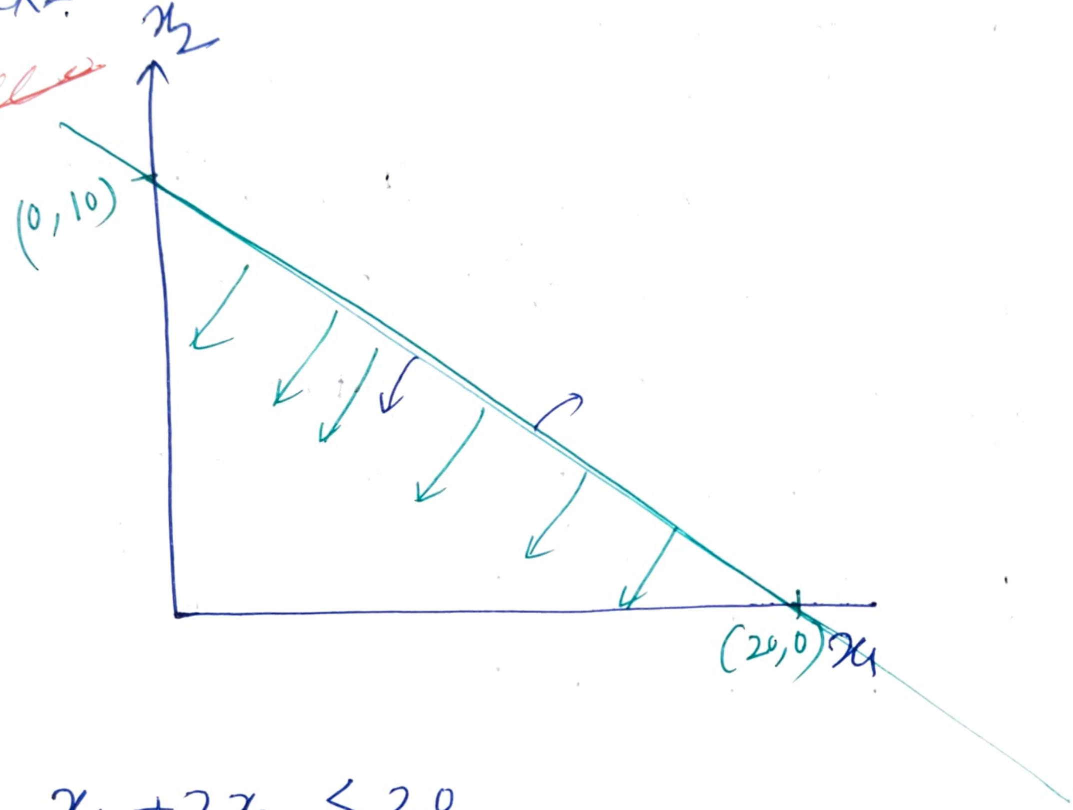
C_j = Profit co-efficient

x_j = Decision variable

b_i = Resource value

a_{ij} = Technological coefficient.

ex:-



$x_1 + 2x_2 \le 20$

If $x_1 = 0$ $x_2 = 10$ (0, 10)

If $x_2 = 0$ $x_1 = 20$ (20, 0)

Put (0, 0) in $x_1 + 2x_2 \le 20$

$0 \le 20$ (Satisfy)

If not satisfy then opposite side.

As satisfy so ↙↙↙ regions

OM

Q-51 A Company produces two types of toys : P and Q production time of Q is twice that of P and the company has a maximum of 2000 time units per day. The supply of raw material is just sufficient to produce 1500 toys (of any type) per day. Toy type Q requires an electric switch which is available at 600 pieces per day, only. The company makes a profit of Rs 3 and Rs 5 on type P and Q respectively. for maximization of profits, the daily production quantities of P and Q toys should respectively be :-

(A) 1000, 500 (B) 500, 1000

(C) 800, 600 (D) 1000, 1000

	x_1 P	x_2 Q	Resources
Time	1	2	2000
(Quantity/ Capacity)	1	1	1500
Switch	0	1	600
Profit/unit	3	5	

Objective fn :-

$$\boxed{Z = 3x_1 + 5x_2}$$

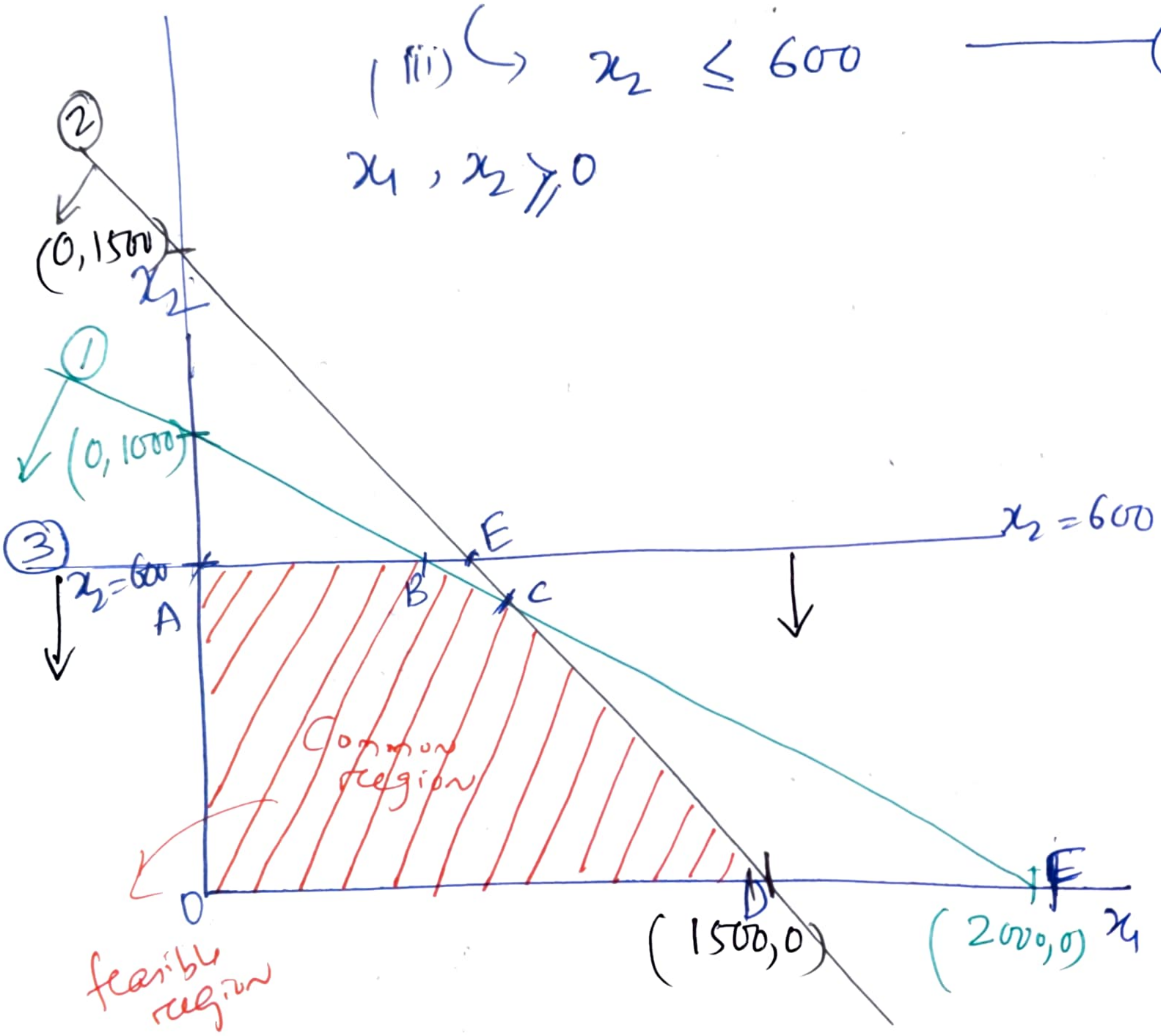
Constraints (i) $x_1 + 2x_2 \leq 2000$ ——— ①

(ii) $x_1 + x_2 \leq 1500$ ——— ②

$0x_1 + 1x_2 \leq 600$

(iii) ↳ $x_2 \leq 600$ ——— ③

$x_1, x_2 \geq 0$



$x_1 + 2x_2 = 2000$ ~~if~~ when $x_1 = 0$, $x_2 = 1000$

$x_2 = 0$, $x_1 = 2000$

(0, 1000) & (2000, 0) points.

OM

For (ii) Constraint

$$x_1 + x_2 = 1500$$

If $x_1 = 0$, $x_2 = 1500$

If $x_2 = 0$ $x_1 = 1500$

points are $(0, 1500)$

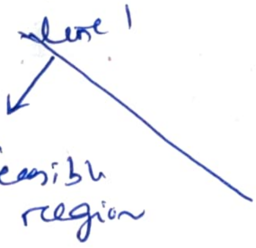
$(1500, 0)$

For (iii) Constraint $x_2 = 600$

Now we need to find the feasible region by putting (0, 0) in eqn (i), (ii) & (iii)

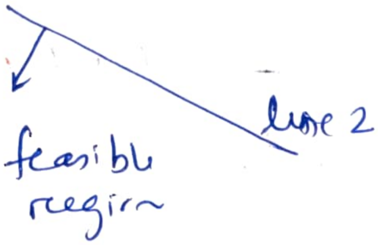
$x_1 + 2x_2 \leq 2000$

$0 + 2\times0 \leq 2000$ ✓ $2 < 2000$



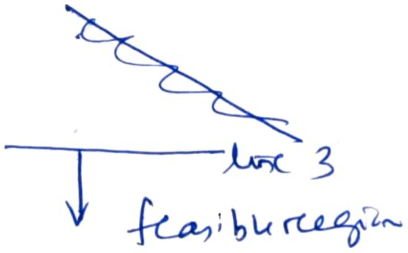
$x_1 + x_2 \leq 1500$

$\therefore 0 + 0 \leq 1500$ ✓



$x_2 \leq 600$

$0 \leq 600$ ✓



$\underline{\underline{OM}}$

feasible region is OABCD with corner points A, B, C, D;

These corner point values has to be put in Z and which is maximum that is the answer.

pt A → (0,600)

pt 'B' is the c/s of line 1 & line 3.

$x_1 + 2x_2 \leq 2000$

$x_2 \leq 600$

Put $x_2 = 600$ in the eqn

$x_1 = 2000 - 1200 = 800$

So pt B is $(800, 600)$

Similarly pt C is the c/s of line 1 & line 2

$x_1 + 2x_2 \leq 2000$

$x_1 + x_2 \leq 1500$

i.e $(x_1, x_2) \rightarrow (1000, 500)$

$\underline{\text{Solve it}}$

$$\begin{array}{r} x_1 + 2x_2 = 2000 \\ - \; x_1 + x_2 = 1500 \\ \hline x_2 = 500 \end{array}$$

$x_1 = 1500 - 500$

$= 1000$

pt C → $(1000, 500)$

& pt D → $(1500, 0)$

OM

$A = (0, 600)$

$B = (800, 600)$

$C = (1000, 500)$

$D = (1500, 0)$

$Z = 3x_1 + 5x_2$

$Z(0, 600) = \overset{3\times0+5\times600}{~~3\times0+5\times600~~} = 3000$

$Z(800, 600) = 3\times800 + 5\times600 = 5400$

$Z(1000, 500) = 3\times1000 + 5\times500 = \boxed{5500}$ max profit

$Z(1500, 0) = 3\times1500 + 5\times0 = 4500$

Answer is → (1000, 500) Answer ✓

Alternate method

Slope method

$y = mx + c$

m ↳ Slope

<u>04</u>

$Z = 3x_1 + 5x_2$

$m_Z = \frac{-3}{5} = -0.6$ $\boxed{m_Z = -0.6}$

$[\ y = mx + c$

$5x_2 = -3x_1 + Z$

$\Rightarrow x_2 = \left(\frac{-3}{5}\right) x_1 + (1/5) Z\ ]$

Constraint (1)

$x_1 + 2x_2 \leq 2000$

$2x_2 = -x_1 + 2000$

$\Rightarrow x_2 = -0.5\, x_1 + 1000$

$\boxed{m_1 = -0.5}$

Constraint (2)

$x_1 + x_2 \leq 1500$

$x_2 = -x_1 + 1500$

$\therefore \boxed{m_2 = -1}$

Constraint 3

$x_2 \leq 600$

$y = mx + c$

$x_2 = m x_1 + 600$ $\boxed{m_3 = 0}$

Then check m_2 slope is lies in between which two lines.

m_3	m_1	m_2
0	−0.5	−1

−0.6 lies in between this two.

i.e objective fn slope lies in between line 1 & line ~~3~~ 2

$$x_1 + 2x_2 \le 2000$$
$$x_1 + x_2 \le 1500$$

Solve it

$$\cancel{x_1} + 2x_2 = 2000$$
$$- \quad \cancel{x_1} + x_2 = 1500$$
$$x_2 = 500$$

$$x_1 = 2000 - 2 \times 500$$
$$= 1000$$

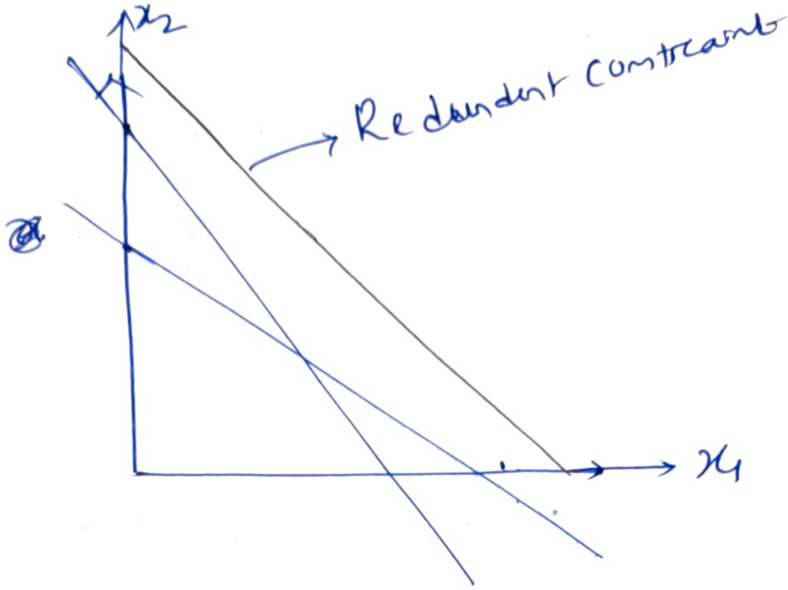
$\therefore$ pt $(1000, 500)$

i.e w/o doing any graph we can solve directly by using slope method

But one limitation is there!

Limitation ⇒

» There will be no redundent in the problem



Redudendent constraint when doesnot become the part of feasible region.
↳ Boundary

(x_1) · (x_2)

Q52 Two models P and Q of a product earn profit of Rs 100 and Rs 80 per piece, respectively. Production times for P & Q are 5 hours and 3 hours respectively, while the ~~total~~ total prodn. time available is 150 hours, for a total batch size of 40., to maximize profit, the no. of units of P to be produced is ______.

Consider the following linear programming problem (LPP)

Ans

$$Z = 100x_1 + 80x_2$$

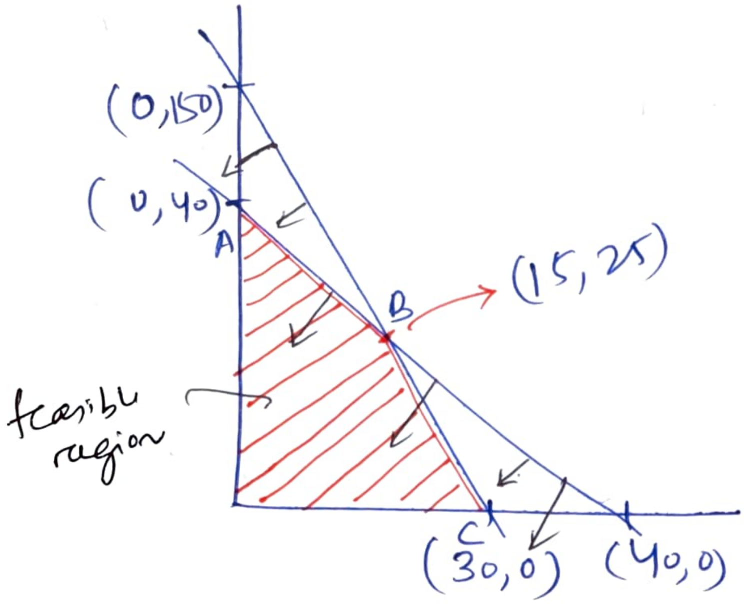
Constraints

$$5x_1 + 3x_2 \le 150$$

$$P + Q = 40$$

ie $x_1 + x_2 = 40$

If $x_1 = 0 \Rightarrow x_2 = 150$	$x_1 + x_2 = 40$
$x_2 = 0, \; x_1 = 30$	pts $(0,40)$ & $(40,0)$
Pts $(0,150)$ $(30,0)$	



$$5x_1 + 3x_2 = 150$$

$$3[\underline{x_1} + \underline{x_2} = 40$$

$$2x_1 = 150 - 120$$

$$\Rightarrow x_1 = 30/2 = 15$$

$$\therefore x_2 = 40 - 15$$

$$= 25$$

$$\therefore (15, 25)$$

$Z = 100x_1 + 80x_2$

$\therefore$ Z at A $= 100 \times 0 + 80 \times 40 = 3200$

Z at B $= 100 \times 15 + 80 \times 25 = 3500$ ✓

Answer is $(15, 25)$ ie $P \rightarrow 15 \ (x_1)$

$Q \rightarrow 25 \ (x_2)$

$P \rightarrow 15$ (Ans)

Binding Constraint

Let pt (A) → our objective fn is optimized.

put pt A in Constraint eqn

if RHS = LHS constraint is called Binding

otherwise non binding.

example :- (From previous problem)

$(x_1, x_2) = (1000, 500)$ Z is optimized.

in that both ~~eq~~ line 1 & line 2 are binding as RHS = LHS

But line 3 is non-binding as RHS ≠ LHS

Special Case ⇒

① Unique soln ⇒

When slope of objective eqn (m_Z) ≠ slope of any of the constraint

ex + $m_Z = -0.6$

$m_1 = -0.5$ We will get

$m_2 = -1$ unique soln

$m_3 = 0$

② Multiple optimal soln (More than one) ⇒

when m_Z = slope of any of the constraint

⇓

Now we have chance of getting more than one soln i.e multiple optimal.

must be there, along with above both (below) condn

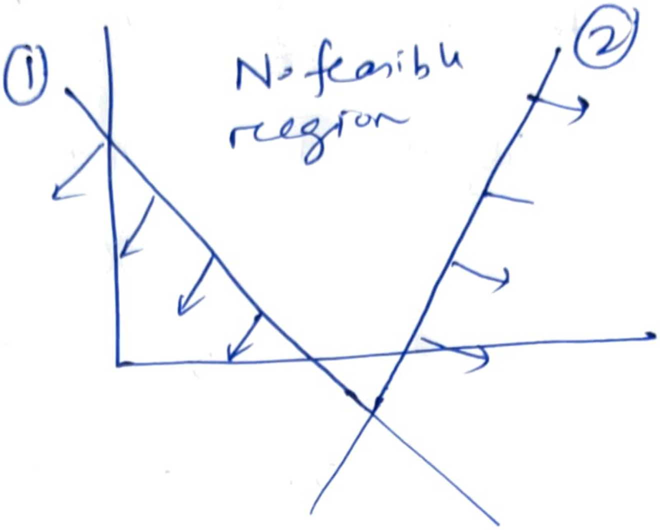
① Constraint must be a binding constraint.

② Constraint must be a non-redundant constraint.

OM

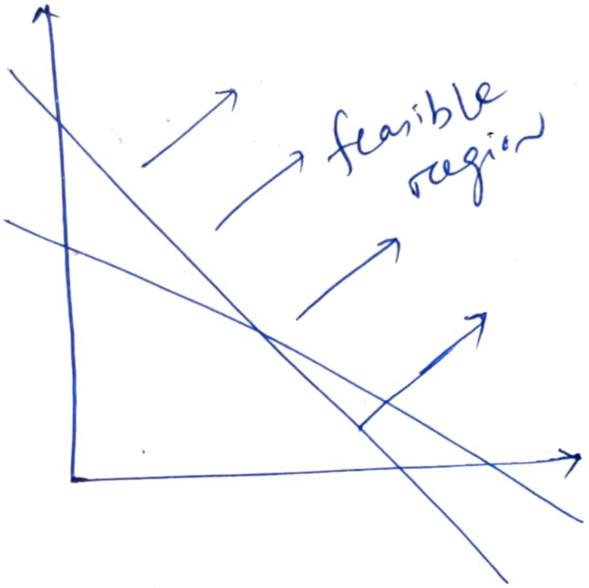
③ No Solution ⇒

When No feasible region available



④ Unbounded Solution ⇒

When greatest value lies at infinity in the problem (Maximization)



Q-53 Consider the following linear programming problem (LPP):

Maximize $Z = 3x_1 + 2x_2$

Subject to $3x_1 + 2x_2 \leq 18$

$x_1 \leq 4$

$x_2 \leq 6$

$x_1 \geq 0, \quad x_2 \geq 0$

(A) The LPP has a unique optimal soln

(B) The LPP is ~~fea~~ infeasible (No soln)

(C) The LPP is unbounded.

(D) The LPP has multiple optimal soln

$Z = 3x_1 + 2x_2$

Constraints $3x_1 + 2x_2 = 18$

$x_1 = 4$

$x_2 = 6$

$m_Z = ?$ $\quad y = mx + c$

$x_2 = -3/2\, x_1 + 1/2\, c$

$$\boxed{m_Z = -3/2}$$

OM

(19)

Constraint 1

$$3x_1 + 2x_2 = 18$$

$y = mx + c$ $\qquad 2x_2 = 18 - 3x_1$

$$\Rightarrow x_2 = -3/2\, x_1 + 18/2$$

$\therefore \boxed{m_1 = -3/2}$

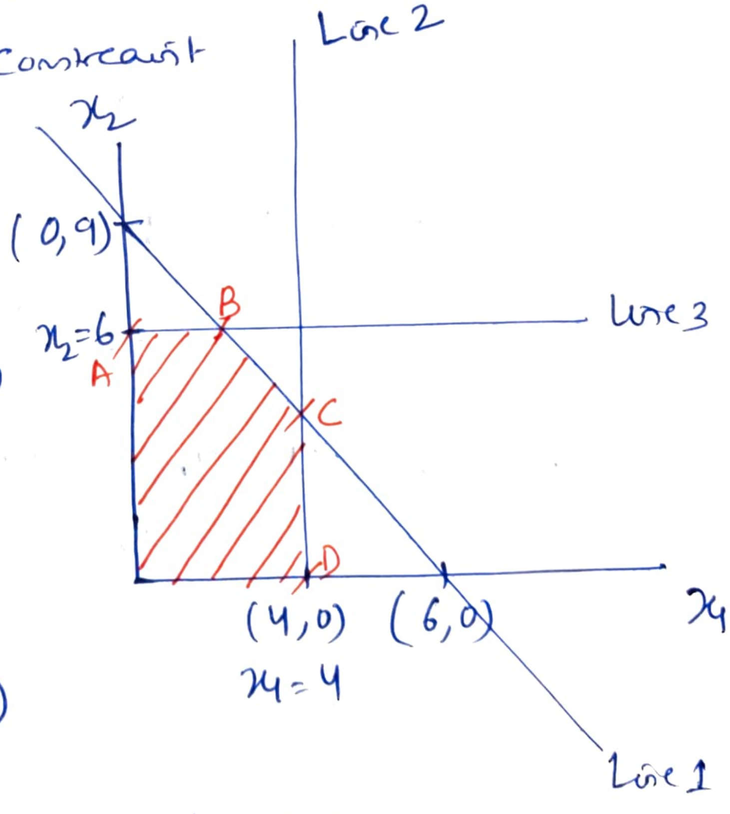
$\therefore$ Here we can see $m_2 = m_1$

$\Downarrow$

Chance of multiple optimal with two condⁿ

(i) Non-redundent

(ii) Binding constraint



For 1st Constraint

$3x_1 + 2x_2 = 18$

pts are when $x_1 = 0$

$x_2 = 9$

When $x_2 = 0$, $x_1 = 6$

$\therefore$ pts are

(0, 9) & (6, 0)

(i) Satisfied Non-redundent

OM

∴ $Z_A = 12$ at $(0, 6)$

$Z_B = 18$ at $(2, 6)$

$Z_C = 18$ at $(4, 3)$

$Z_D = 12$ at $(4, 0)$

at $(2, 6)$ $Z = 3x_1 + 2x_2 = 18$

$= 3 \times 2 + 2 \times 6$

$\Rightarrow 18 = 18$

at $(4, 3)$ $3x_1 + 2x_2 = 18$

$\Rightarrow 3 \times 4 + 2 \times 3 = 18$

$\Rightarrow 18 = 18$

i.e Condn (ii) Binding Constraint also satisfied.

Ans is: (D) The LPP has multiple optimal solution.

Q 54 For the linear programming problem:

Maximize $Z = 3x_1 + 2x_2$

Subject to $-2x_1 + 3x_2 \leq 9$

$x_1 - 5x_2 \geq -20$

$x_1, x_2 \geq 0$

The above problem has:

(A) Unbounded Sol^n

(B) Infeasible Sol^n

(C) Alternative optimal Sol^n

(D) Degenerate solution.

Maximize $Z = 3x_1 + 2x_2$

$-2x_1 + 3x_2 \leq 9$

$-x_1 + 5x_2 \leq 20$

$x_1, x_2 \geq 0$

resource value cannot be in -ve so multiply -ve in both sides of constraint (ii), we will get the eqn.

OM

$m_Z = ?$

$2x_2 = -3x_1 + Z$

$\Rightarrow x_2 = -3/2\, x_1 + (1/2)\, Z$

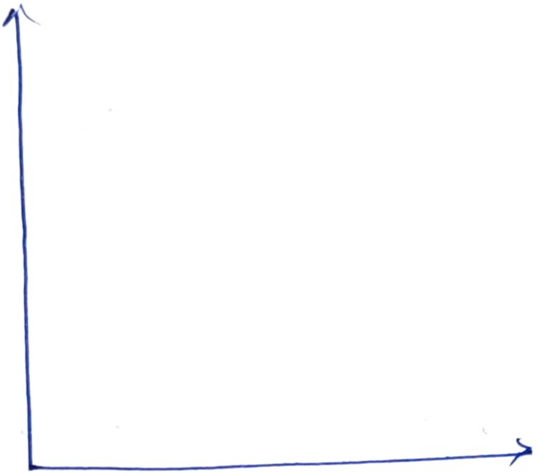
$m_Z = -3/2$

For constraint (i)

$m_1 = +2/3$

For constraint (ii)

$m_2 = 1/6$



$-2x_1 + 3x_2 = 9$

at $x_1 = 0$, $x_2 = 3$

$x_2 = 0 \quad x_1 = -9/2$

$(0, 3)$ & $(-9/2, 0)$

$\Downarrow$

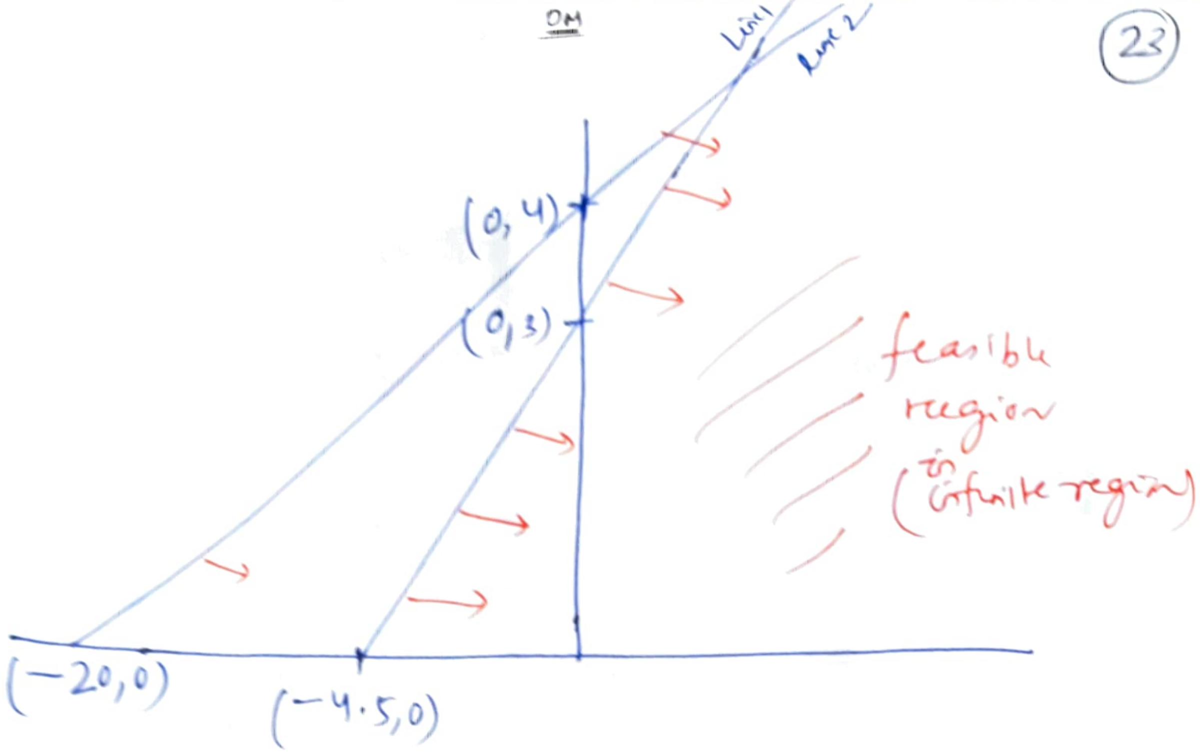
$(-4.5, 0)$

$x_1 - 5x_2 = -20$

$x_1 = 0$, $x_2 = 4$

$x_2 = 0$, $x_1 = -20$

$(0, 4)$ $(-20, 0)$



Ans- Unbounded Solution

Q. 50 A manufacturer produces two types of products 1 and 2, at production levels of x_1 & x_2 respectively.

The profit is given as $2x_1 + 5x_2$

The production constraints are:

$$x_1 + 3x_2 \leq 40$$

$$3x_1 + x_2 \leq 24$$

$$x_1 + x_2 \leq 10$$

$$x_1, x_2 > 0$$

The maximum profit which can meet the constraints is (A) 29 (B) 38 (C) 44 (D) 75

Simplex Method

Analytical method

adv^n ÷ 2 or more than two variables can be solved.

→ adv^n ÷ Step by step procedure where in every steps we improve the sol^n.

→ Iterative process.

Objective function
Constraints
Resource value non-negative

Steps Convert inequalities to equations.
~~Initial Basic soln~~ and Convert to equality.

$$Z = 2x_1 + 8x_2$$

ex ÷ $3x_1 + 4x_2 \leq 12$

$$6x_1 + 8x_2 \leq 11$$

Convert to Equalities

LHS $\leq$

So we add

$$3x_1 + 4x_2 + \textcircled{S_1} = 12$$

→ Slack variable

$$6x_1 + 8x_2 + S_2 = 11$$

If $x_1 + 2x_2 \geq 6$

So $x_1 + 2x_2 - S_1 = 6$

Convert to equality

→ Surplus variable

Objective f^n will be then ON

$$Z = 2x_1 + 8x_2 + 0S_1 + 0S_2$$

ex÷

$$Z = 2x_1 + 8x_2 + 0S_1 + 0S_2$$

Constraint $3x_1 + 4x_2 + S_1 = 12$

From
Objective f^n & 2 Constraints

we can se 4 unknown
Variable x_1, x_2, S_1 & S_2

& Constraint '2'

So we cannot solve.

As '4' unknown so we reqr
four equation.

So, Let m = Constraint = 2

n = Variable = 4

$$n - m = 0$$

$$4 - 2 = \boxed{2} = 0$$

↳ if two variables = 0
2 Variables = 0

x_1, S_1 or x_1, S_2
or x_2, S_2

OM

③

~~A~~ Let 3 constraints are there

3 variable + 2

then also same situation, we cannot solve the eqn to find out variable.

$$^{n}C_{m} = {}^{4}C_{2} = 6$$

↳ No. of soln

Initial Basic feasible soln ⇒

Let $\boxed{\begin{array}{l} x_1 = 0 \\ x_2 = 0 \end{array}}$ ⇒ $\boxed{\begin{array}{l} s_1 = 12 \\ s_2 = 11 \end{array}}$

⇓ Non basic variable

⇓ Basic variable

$\boxed{\begin{array}{l} x_1 = 0 \\ s_1 = 0 \end{array}}$ ⇒ Non basic variable

$x_2 = 4$

⇒ Basic variable

$s_2 = 4$

OM

Q A toy manufacturing company

Toy

	~~Resource value~~		Resource value
	Car	Auto	
material	2	1	100 kg
Wheel	4	3	240 wheels.
Profit/Unit	7	5	

maximize $Z = 7x_1 + 5x_2$

$2x_1 + x_2 \leq 100$

$4x_1 + 3x_2 \leq 240$

$x_1, x_2 \geq 0$

Convert to simplex form

Inequality to equality

$2x_1 + x_2 + S_1 = 100$

$4x_1 + 3x_2 + S_2 = 240$

Maximization $Z = 7x_1 + 5x_2 + 0S_1 + 0S_2$

$n = 4 \Rightarrow x_1, x_2, S_1, S_2$

$m = 2 \Rightarrow$ Constraint $= 2$

i.e $n - m = 2$ variables we have to take zero.

$$\left.\begin{array}{l} \text{Let } x_1 = 0 \\ x_2 = 0 \end{array}\right\} \Rightarrow \boxed{\begin{array}{l} S_1 = 100 \\ S_2 = 240 \end{array}}$$

x_1, x_2 = Non basic

S_1, S_2 = Basic variable

Then we will make the table :-

	C_j	7	5	0	0	b_i	θ_i
Coeffiant	Basic	x_1	x_2	S_1	S_2	Sol^n	$\left(\frac{\text{Sol}^n}{a_{ij}}\right)$
0	S_1	②	1	1	0	100	$100/2 = 50$
0	S_2	4	3	0	1	240	$240/4 = 60$
	Z_j	0	0	0	0		
	$\Delta_j = C_j - Z_j$	$\boxed{7}$	5	0	0		

Key element or pivot element

Net evaluation row or Net oppertunity cost row

Key column Incoming variable

Key row (Value min)

Min ratio Column ← outgoing variable (S$_1$ out & x_1 enter)

$$\boxed{Z_j = \sum x_i C_i}$$

for x_1, $Z_j = 2\times0 + 4\times0 = 0$

for x_2, $Z_j = 1\times0 + 3\times0 = 0$

Δ_j has three Sol^n +ve, −ve, Zero

if +ve ⇒ Sol^n improve & for maximization problem, we need to take the most +ve value.

if −ve ⇒ Sol^n decrease & for minimization, we will have to take the most −ve value.

Zero ⇒ No effect

OM

θ_i = Replacement ratio = $\frac{Sol^n}{a_{ij}}$

Condn: For maximization if Δj = −ve/zero problem is optimized.

Just opposite For minimization if Δj = +ve/zero problem is optimized.

If in θ_i row = if −ve / infinity come then we will not consider that (X)

	C_j	7	5	0	0		
	Basis	x_1	x_2	S_1	S_2	Soln	θ
7	x_1	1	$1/2$	$1/2$	0	50	100
0	S_2	0	$\boxed{1}$	−2	1	40	40 ←
	Z_j	7	$7/2$	$7/2$	0		
	$\Delta_j = C_j - Z_j$	0	$3/2$	$-7/2$	0		

Divide by keyelement

↑ Key column (Incoming variable)

New no. = Old No − $\frac{\text{(Corresponding row element} \times \text{Corresponding column element)}}{\text{Key element}}$

$= 4 - \frac{2 \times 4}{2} = 0$

$3 - \frac{4 \times 1}{2} = 1$

	C_j	7	5	0	0		
	Basis	x_1	x_2	S_1	S_2	Solⁿ	θ
7	x_1	1	0	$3/2$	$-1/2$	30	
5	x_2	$0/1$	$1/1$	$-2/1$	$1/1$	40	
	Z_j	7	5	$1/2$	$3/2$		
	$\Delta_j = C_j - Z_j$	0	0	$-1/2$	$-3/2$		

$\Downarrow$

Now no value is +ve

ie Our problem is optimized.

$x_1 = 30, \quad x_2 = 40$

$Z = 7 \times 30 + 5 \times 40 = 410$

Special case ⇒

(1) Multiple optimal solⁿ ⇒ infinite

when in Δ_j row value of non-basic variable value is zero in optimal solⁿ.

Basis	x_1	x_2	S_1	S_2
x_1				
x_2				
Δ_j			0	0

multiple optimal solⁿ or infinite

OM

② **Unbounded Solution ⇒**

Replacement ratio column

Basis	x_1	x_2	S_1	S_2	θ
x_1					-ve or ∞
x_2					-ve or ∞
					-ve or ∞

⇓

Unbounded Soln

③ **No solution or infeasibility ⇒**

A_1 ⇒ Artificial variable

or in final Soln → Artificial variable present

⇒ No solution

— · —

⊗ In maximization if Δj ⇒ 0 or -ve then problem optimized

⊗ In minimization Δj ⇒ 0 or +ve then problem optimized.

Dual of LPP ⇒

Primal ⇒ matrix transpose ⇒ Dual

Solution same

c_j convert to b_j

$$\max Z = \textcircled{7}x_1 + 5x_2$$

$2x_1 + x_2 \le 100$ $b_j \to c_j$ in dual

$4x_1 + 3x_2 \le 240$

$x_1, x_2 \ge 0$

b_j = Resource value

c_j → Profit Co-efficient

	Car	Auto	Resource
mat	A	B	
wheel	2	1	100
	4	3	240
Profit	7	5	

Primal problem

Convert to Dual   Rule No. ① maximization problem convert ⇒ ≤

minimization convert to ⇒ ≥

Primal		Dual
max	Convert →	min
min	→	max
b_j	→	c_j
c_j	→	b_j
constraint m	→	n
variable n	→	m

Convert

≥ ⇒ ≤

≤ ⇒ ≥

om

Dual (What is Dual)?

~~minimization~~

		A	B	
Y_1	mat	2	1	100
Y_2	Wheel	4	3	240
		7	5	

$$\text{minimization } Z = 100y_1 + 240y_2$$

$$2y_1 + 4y_2 \geq 7$$

$$y_1 + 3y_2 \geq 5$$

$$y_1, y_2 \geq 0$$

$C_j \rightarrow b_j$

& $b_j \rightarrow C_j$

From previous problem we can see →

				y_1	y_2	
	Basis	7	5	0	0	
		x_1	x_2	S_1	S_2	
7	x_1	1	0	3/2	-1/2	30
5	x_2	0	1	-2	1	40
	Z_j	7	5	1/2	3/2	
	$\Delta_j = C_j - Z_j$	0	0	$\bigcirc\!\!\!\!-1/2$	$\bigcirc\!\!\!\!-3/2$	

→ Shadow price or Unit worth or Dual price

$Y_1 = 1/2$ (No negative)

$Y_2 = 3/2$

→ $Z = 50 + 360$

$= 410$

primal & Dual Soln Same

Q Consider the Linear programming (LP)

maximum $Z = 4x + 6y$

Subject to $3x + 2y \leq 6$

$2x + 3y \leq 6$

$x, y \geq 0$

After introducing slack variables s and t, the initial basic feasible soln is represented by the table below (basic variables are s = 6, t = 6) and the objective function value is 0.

	-4	-6	0	0	0
s	3	2	1	0	6
t	2	3	0	1	6
	x	y	s	t	RHS

$\Delta_j = Z_j - C_j$

OM

After some Simplex iterations, the following table is obtained.

Δj

	0	0	0	-2	12
S	5/3	0	1	-1/3	2
y	2/3	1	0	1/3	2
	x	y	s	t	RHS

problem optimize

Basic value

Non basic Variable

x, t

From this, one can conclude that

(A) The LP has a unique optimal soln

✓ (B) The LP has an optimal soln that is not unique

(C) The LP is infeasible

(D) The LP is unbounded.

or find out the slope of all

$m_Z = -2/3$

$m_1 = -3/2$

$m_2 = -2/3$ $\quad m_Z = m_2$

Again x & t ⇒ Non Basic variable

x = 0 in graph so infinite soln.

OM

⑬

Q-56 The dual for the LP is above is

(a) min $6u+6v$ subjected to

$3u+2v \geq 4,\ 2u+3v \geq 6,\ u, v, \geq 0$

(b) Min $6u+6v$ subjected to

$3u+2v \leq 4,\ 2u+3v \leq 6,\ u, v \geq 0$

(c) Min $4u+6v$ subjected to

$3u+2v \geq 6,\ 2u+3v \geq 6,\ u, v \geq 0$

(d) Min $4u+6v$ subjected to

$3u+2v \leq 6,\ 2u+3v \leq 6,\ u; v \geq 0$

Let $x = u$ & $y = V$

~~Minimization $Z = 6u+6v$~~

$C_j \rightarrow b_j$

$b_j \rightarrow C_j$

in question

Maximize	minimize
$Z = 4x+6y$	$Z = 6u+6v$
$\overset{u}{3x} + \overset{v}{2y} \leq 6$	$3u+2v \geq 4$
$2x+3y \leq 6$	$2u+3v \geq 6$
$x, y \geq 0$	$u, v \geq 0$

Option (a) is the correct answer.

OM

⊛ Dual of Dual is primal

⊛ If primal → Infeasible Soln

⇒ Dual → Solution Unbounded

or infeasible

⊛ If primal $\xrightarrow{\text{Soln}}$ is Unbound

⇒ Dual $\xrightarrow{\text{Soln}}$ is 100% infeasible

Module-IV Operations Management Processes (09 Hours)

Process selection strategies and process lifecycle. Work study: Method study: process chart symbols, flow process charts. Time study: stopwatch method, standard time calculation.

Value engineering and value analysis: definition, procedure, benefits. Materials Requirement Planning (MRP I) and MRP II: logic and structure. TOC (Theory of Constraints) and Critical Chain Project Management (CCPM). Line balancing: objectives, heuristics, practical examples. Forecasting: types (qualitative vs quantitative), methods (moving average, exponential smoothing, regression models).

Process Selection Strategies

Process selection is the strategic decision of choosing the type of production process that best fits the product volume, variety, and demand characteristics.

The objective is to achieve low cost, high quality, flexibility, and timely delivery.

Job Shop Process

- **Low volume, high variety**
- Customized products
- General-purpose machines
- Skilled labour

Examples: Tool rooms, hospitals, repair workshops

Strategy used when:

- Demand is uncertain
- High customization required

Batch Process

- **Moderate volume, moderate variety**
- Production in batches
- Some standardization

Examples: Pharmaceuticals, garments, bakery products

Strategy used when:

- Products have similar processing needs
- Demand is periodic

Assembly Line (Mass Production) Process

- **High volume, low variety**
- Standardized products
- Specialized equipment

Examples: Automobile assembly, consumer electronics

Strategy used when:

- Demand is stable and high
- Low unit cost is critical

Continuous Process

- **Very high volume, very low variety**
- Continuous flow of material
- Highly automated

Examples: Oil refining, cement, steel, power plants

Strategy used when:

- Demand is continuous
- Shutdowns are costly

Project Process

- **One-time, large-scale activities**

- Fixed location
- High customization

Examples: Construction of bridges, ships, power plants

Hybrid Process

- Combination of two or more processes

Examples:

- Automobile manufacturing (assembly line + job shop)
- Hospitals (job shop + batch)

Process–Product Matrix

Product Volume	Product Variety	Suitable Process
Low	High	Job Shop
Medium	Medium	Batch
High	Low	Assembly Line

Very High	Very Low	Continuous

Process Life Cycle

The **process life cycle** explains how **manufacturing processes evolve** as the product moves through its **product life cycle**.

Introduction Stage

- Low demand
- High product variety
- Flexible processes

Process Used:
Job shop / Project process

Characteristics:

- High cost

- Frequent design changes
- Skilled labour

Growth Stage

- Increasing demand
- Some standardization
- Improved efficiency

Process Used:
Batch process

Characteristics:

- Moderate cost
- Increased automation
- Better scheduling

Maturity Stage

- Stable, high demand
- Standardized product
- Cost minimization focus

Process Used:
Assembly line / Mass production

Characteristics:

- Low unit cost
- High efficiency
- Specialized equipment

Decline Stage

- Falling demand
- Reduced variety
- Excess capacity

Process Strategy:

- Process simplification
- Automation reduction
- Possible shutdown or product replacement

Product–Process Life Cycle Relationship

Product Life Cycle Stage	Process Type
Introduction	Job Shop
Growth	Batch
Maturity	Assembly Line
Decline	Continuous / Rationalized

Product Life Cycle

Product life cycle (PLC) defines the stages that products moves through as they enter, get established in and ultimately leave the market place.

The life cycle of a product is associated with marketing and management decisions within businesses, and all products go through five primary stages: development, introduction, growth, maturity, and decline. Each stage has its costs, opportunities, and risks, and individual products differ in how long they remain at any of the life cycle stages.

1. Development

The product development stage is often referred to as “the valley of death.”

At this stage, costs are accumulating with no corresponding revenue.

Some products require years and large capital investment to develop and then test their effectiveness.

Since risk is high, outside funding sources are limited.

While existing companies often fund research and development from revenue generated by current products, in start-up businesses, this stage is typically funded by the entrepreneur from their own personal resources.

2. Introduction

The introduction stage is about developing a market for the product and building product awareness.

Marketing costs are high at this stage, as it is necessary to reach out to potential customers.

This is also the stage where intellectual property rights protection is obtained.

Product pricing may be high to recover costs associated with the development stage of the product life cycle, and funding for this stage is typically through investors or lenders.

3. Growth

In the growth stage, the product has been accepted by customers, and companies are striving to increase market share.

For innovative products there is limited competition at this stage, so pricing can remain at a higher level.

Both product demand and profits are increasing, and marketing is aimed at a broad audience.

Funding for this stage is generally still through lenders, or through increasing sales revenue.

4. Maturity

At the mature stage, sales will level off.

Competition increases, so product features may need to be enhanced to maintain market share.

While unit sales are at their highest at this stage, prices tend to decline to stay competitive.

Production costs also tend to decline at this stage because of more efficiency in the manufacturing process.

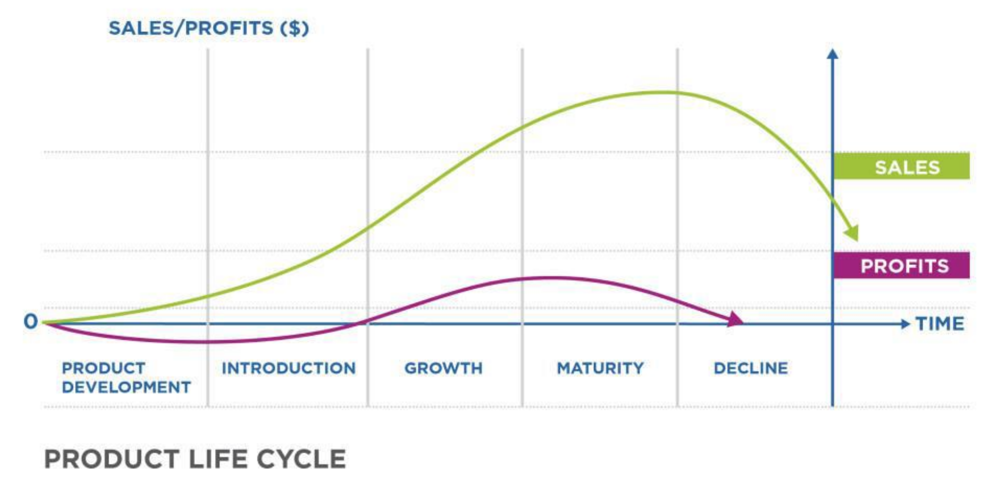
Companies usually do not need additional funding at this stage.

5. Decline

The decline stage of the product life cycle is associated with decreasing revenue due to market saturation, high competition, and changing customer needs.

Companies at this stage have several options: They can choose to discontinue the product, sell the manufacturing rights to another business that can better compete or maintain the product by adding new features, finding new uses for the product, or tap into new markets through exporting.

This is the stage where packaging will often announce “new and improved.”



PRODUCT LIFE CYCLE

Product Life Cycle Examples

The traditional product life cycle curve is broken up into four key stages. Products first go through the Introduction stage, before passing into the Growth stage. Next comes

Maturity until eventually the product will enter the Decline stage. These examples illustrate these stages for particular markets in more detail.

3D Televisions: 3D may have been around for a few decades, but only after considerable investment from broadcasters and technology companies are 3D TVs available for the home, providing a good example of a product that is in the Introduction Stage.

Blue Ray Players: With advanced technology delivering the very best viewing experience, Blue Ray equipment is currently enjoying the steady increase in sales that’s typical of the Growth Stage.

DVD Players: Introduced a number of years ago, manufacturers that make DVDs, and the equipment needed to play them, have established a strong market share. However, they still have to deal with the challenges from other technologies that are characteristic of the Maturity Stage.

Video Recorders: While it is still possible to purchase VCRs this is a product that is definitely in the Decline Stage, as it’s become easier and cheaper for consumers to switch to the other, more modern formats.

Another example within the consumer electronics sector also shows the emergence and growth of new technologies, and what could be the beginning of the end for those that have been around for some time.

Holographic Projection: Only recently introduced into the market, holographic projection technology allows consumers to turn any flat surface into a touchscreen interface. With a huge investment in research and development, and high prices that will only appeal to early adopters, this is another good example of the first stage of the cycle.

Tablet PCs: There are a growing number of tablet PCs for consumers to choose from, as this product passes through the Growth stage of the cycle and more competitors start to come into a market that really developed after the launch of Apple’s iPad.

Laptops: Laptop computers have been around for a number of years, but more advanced components, as well as diverse features that appeal to different segments of the market, will help to sustain this product as it passes through the Maturity stage.

Typewriters: Typewriters, and even electronic word processors, have very limited functionality. With consumers demanding a lot more from the electronic equipment they buy, typewriters are a product that is passing through the final stage of the product life cycle.

OM

Work study

Effectiveness ↑ → Productivity ↑

→ 2 method

Lesser time

Lesser effort (Labour time less)

Work study refers to a systematic examination of work methods aimed at improving productivity and efficiency. It involves analyzing how tasks are performed, identifying areas for improvement and implementing changes to streamline processes.

Work study typically includes methods like time and motion study, work measurement & ergonomic assessments to optimize workflow, reduce waste and enhance overall productivity in various industrial & service sectors.

Work study

- Motion study or Method study (Lesser effort)
  finding out alternate method to work with lesser effort.
- Time study or Work measurement (Lesser time)

Motion Study ⇒

group of activity

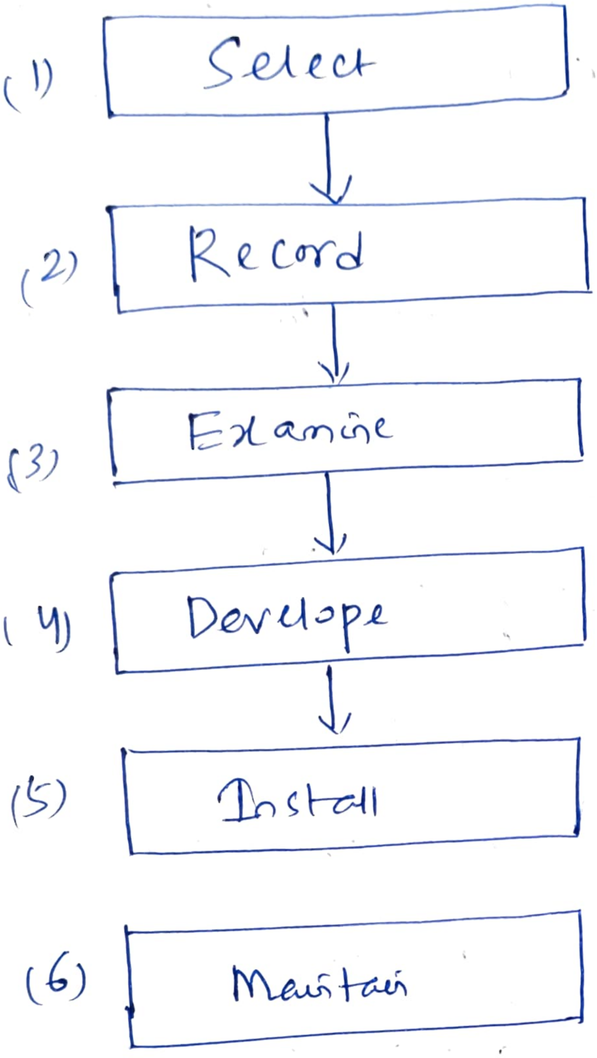
⇓

to find alternate method

Motion study is a part of work study that focuses on improving the efficiency of a task by analyzing the movements involved in performing it.

Motion study is the systematic observation, analysis, and improvement of the movements of workers or m/cs in order to eliminate unnecessary motions and develop the most efficient method of doing a job.

Steps / Method of motion study ⇒



(1)	Select	Job select
(2)	Record	Record all data
(3)	Examine	examine recorded data
(4)	Develope	Develope alternate method
(5)	Install	Install best alternate method.
(6)	Maintain	Maintain installed method.

In Recording technique process chart ⇒

Symbol	Event
D	Delay
⇨	Transportation
△	storage
○	operation
□	Inspection
⧇	operation + Inspection or multiple activity

OM

④

Thereblig Basic units of motion used in motion study to analyze the movements involved in performing a task.

↳ Gilbreath scientist

Basic human movements

⇓

Symbolize to 17 fundamental hand eyemovement

⇓

1 add later

Total Therebligs ⇒ ⑱

Therebligs are used to :-

≫ Identify productivity & unproductive motions

≫ Eliminate unnecessary movements.

≫ Improve efficiency and ergonomics.

Types of Therbligs (Selected 18 types)

 Search

 find

 Select

 Grasp

OM


Hold


Transport Loaded


Transport Empty


position


Assemble


Use


Disassemble


Inspect


preposition


Release Load


Unavoidable Delay

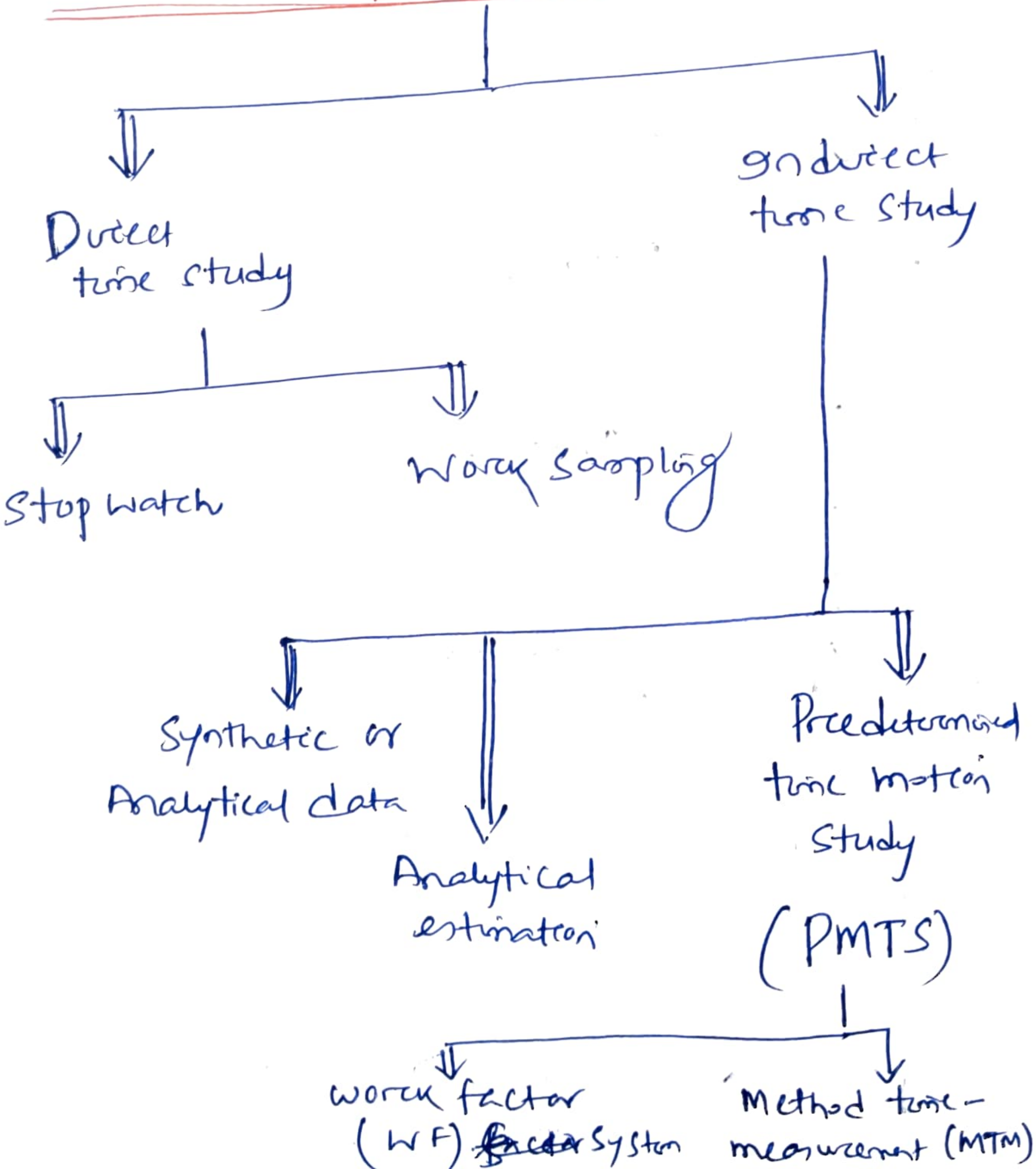
OM


Avoidable Delay


Plan


Rest

Time study or Work measurement ⇒



Stop watch Time study =>

Stop watch is a work measurement technique used to determine the time reqr to perform a task using by stopwatch to record the actual time taken by a worker.

It is commonly used in industrial engineering to set Standard time for manual operations.

purpose of stopwatch time study:

» TO determine the Standard time for completing a task.

» TO identify inefficiencies and improve productivity.

» TO aid in manpower planning, costing and scheduling.

that is called observe time or elemental time.

OM

① Observed / elemental time (OT) ⇒

Observe time to do any job.

② Normal time (NT) ⇒

Time taking by an average worker in normal condition.

ex = Observe time differ from normal time

So we can give ~~Receating~~ Rating factor (RF)

~~ex~~ But in automatic m/c

observed time (OT) = Normal time (NT)

So no rating factor for automatic m/c.

same for all

Let job ⇒ 10 mins (Observe time)

⇒ 12 mins (any person)

↑ skilled / unskilled / or semiskilled

RF = 1.2 i.e 120%.

So NT will differ depending upon the person's capability.

~~NT = OT + RF × OT~~

~~= 10 + 0.2 × 10~~

~~= 12~~

ex:- $OT = 10$ mins

$NT = 10 + 0.2 \times 10$

$= 12$ min

OT

$NT = OT \times R.F$

③ Standard time (ST) ⇒

NT + Allowances ✓

If any worker works for a long time then allowances will be given.

OT → 120%

→ 20% more than observe time worker performance time

Extra time ⇒ Rest, personal work Fatigue, Delay

In company policy 15 mins given after 3 hrs work, Lunch time.

Note ⇒ Allowances always gives with respect to normal time.

ex:- 15% allowances if nothing given.

$ST = NT + 0.15 \times NT$

OM

OT

↓

NT = OT × R.F

↓

ST = NT + Allowances

Q A Soldering operation was work-sampled over two days (16 hours) during which an employee soldered 108 joints, actual working time was 90% of the total time & the performance rating was estimated to be 120 percent. If the contract provides allowance of 20 percent of the total time available, the standard time for the operation would be :

(A) 8 min (B) 8.9 min (C) 10 min

(D) 12 mins

16 hrs ⇒ 108 joints

Actual working time = 90% of total time

RF = 120%

Allowance = 20%.

ST = ?

Actual working time = 90% of

= 16 × 0.9

= 14.4 hr.

Time for single job = $\frac{14.4}{108}$ = $\frac{2}{15}$ hrs

= 0.134 hr

(that is nothing but OT for one job)

i.e OT = $\frac{2}{15}$ hr.

Normal time = $\frac{2}{15} \times RF$ $\boxed{NT = OT \times RF}$

= $\frac{2}{15} \times 1.2$

= 0.16 hr.

Standard time = Normal time + allowances

~~Normal~~ ST = 0.16 ~~hr~~ + (0.16 × 0.2) hr

(∵ allowances of 20% of the total time available)

= 12 min

(a) ST = 12 min

(b) Allowances = 0.16 × 20 hr.

= 0.16 × 20 × 60 min

(c) Normal time = 0.16 hr.

Q.47 A welding operation is time-studied during which an operator was pace-rated as 120%. The operator took on an average, 8 minutes for producing the weld-joint. If a total of 10% allowances are allowed for this operation. The expected standard production rate of the weld joint (in units per 8 hour day) is:

(A) 45 (B) 50 (C) 55 (D) 60

RF = 120%.

Observed time = 8 minute.

Allowances = 10 %.

Expected standard production rate = ?
(in unit per 8 hour day)

ie 8 hr shift.

Available time = 8 × 60 min

= 480 min in one day.

Normal time $NT = OT \times RF$

$NT = 8 \times 1.2$

$= 9.6$ min

$ST = NT + \text{Allowances}$

$= 9.6 + 0.1 \times 9.6$

$ST = 10.56$ min

* As nothing mentioned in question for allowances so by default we have to take for normal time

$$\text{Production rate} = \frac{\text{Available time}}{\text{Standard time taken for 1 job}}$$

$$= \frac{480}{10.56}$$

$$= 45.45$$

✓ Ans :- $\boxed{45}$ complete job.

17.5

A job consists of three work elements and all are performed by the same operator. An analyst conducted work sampling to determine the standard-time for the job. The duration of the study is one shift with 400 minutes of effective time. The details of observations are summarized in table below. The total no. of acceptable units produced during the study period is 150 units. Determine the standard time by assuming allowance of 10 percent.

Data

Work element Number	Frequency of performance	Performance Rating
1	70	80%
2	80	120%
3	50	110%

Soln

Total duration = 400 minutes

Total no. of observations = 200

The calculations for determining normal time & standard time of each of the work elements are summarized in table below.

OM

	Work element 1	2	3
Frequency of performance	70	80	50
P.R	80%	120%	110%
% age of working	$\frac{\text{Frequency of performance}}{\text{Total no. of observations}} \times 100$ $= \frac{70}{200} \times 100 = 35\%$	$\frac{800}{200} \times 100$ $= 40\%$	$\frac{50}{200} \times 100$ $= 25\%$
Normal time (NT) = $\frac{(\text{Total time})(\%\text{ of working}) \times PR}{\text{No. of acceptable units produced}}$	$\frac{400 \times 0.35 \times 0.8}{150}$ $= 0.75$	$\frac{400 \times 0.40 \times 1.2}{150}$ $= 1.28$	$\frac{400 \times 0.25 \times 1.1}{150}$ $= 0.73$
Standard time (ST) $= NT \times AF$ $= NT \times \frac{1}{1 - \text{Percentage allowance}}$ [illegible] (AF = Allowance fraction)	$\frac{0.75}{1 - 0.1}$ $= \frac{0.75}{0.9}$ $= 0.83$	$\frac{1.28}{0.9}$ $= 1.42$	$\frac{0.73}{0.9}$ $= 0.81$

∴ Total standard time of the job $= 0.83 + 1.42 + 0.81$

$= 3.06$ min

Q4

7.6 A job consists of two operations and both are performed by the same operator. The time study engineer decided to conduct work sampling to fix the standard time for the job. The effective shift time is 450 minutes and the no. of acceptable units of the job produced is 15. The details of the observations of the work sampling are shown in table. Determine the standard time of the job by assuming allowance of 10 percent.

Time Study Data

Work element	frequency of performance	Performance rating
1	20	90%
2	30	110%

Effective Shift time = 450 min.

Total no. of observations = 50

As % age of working on a given task

$$= \frac{\text{Frequency of performance of a task}}{\text{Total no. of observations}} \times 100$$

Om

Normal time (NT)

$$= \frac{(\text{Total time})(\text{\% of working})\ \text{PR}}{\text{No. of acceptable units produced}}$$

Standard time (ST)

$$ST = NT \times AF$$

$$= NT \times \frac{1}{1 - \text{percentage allowance)}}$$

AF = Allowance fraction

OM

Summary of calculation of Standard time

	1	2
percentage of working	$\frac{20}{50} \times 100 = 40$ (%)	$\frac{30}{50} \times 100 = 60$ (%)
Actual time spent in minutes for 15 units	450×0.4 $= 180$	450×0.60 $= 270$
Actual time spent per unit in minutes	$\frac{180}{15} = 12$	$\frac{270}{15} = 18$
Normal time in minutes	If we skip the above two rows then $\frac{(\text{Total time})(\%\text{ of working}) \times PR}{\text{No. of acceptable units produced}}$ $= \frac{450 \times 0.4 \times 90\%}{15}$ $= 10.8$	$= \frac{450 \times 0.6 \times 110\%}{15}$ $= \frac{450 \times 0.6 \times 1.1}{15}$ $= 19.8$
Standard time ~~of the job unit~~ in minutes	$\frac{10.8}{1-0.10} = 12$	$\frac{19.8}{1-0.1} = 22$
Standard time of the job/unit in minutes		$= 12+22 = \boxed{34}$ m

OM

17.7

Pawan Sahu

In a binding press, binding of Large size books consist of the following operations:

1. Stitching of the pages
2. Trimming the book
3. Cover making
4. Joining the book with cover & finishing.

The first operation is carried by Mr. Ramesh and the rest of the operations are performed by Mr. Suresh. It is decided to use conventional time study technique for the first operation & work sampling method for the rest of the operations. The effective time available per shift is 480 minutes and the no. of acceptable book binding done this period is 8. The details of the time study data of the first operation are shown in Table1. The performance rating of Mr. Ramesh is 105 percent. The details of the work sampling data shown in table 2.

Table 1 (Time study Date of operation1)

cycle time	18	19	20	21	22
Frequency	2	3	5	4	1

Work sampling data

operation	Frequency performance	performance rating
2	7	120%
3	21	125%
4	22	95%

Find the standard time of the entire job of book binding per book by assuming an allowance of 10 percent to all the operations.

Soln

Time study Data of operation 1

cycle Time in minutes	Frequency	performance Rating
18	2	105%
19	3	
20	5	
21	4	
22	1	

Allowance = 10%

cycle time (CT) = $\dfrac{18 \times 2 + 19 \times 3 + 20 \times 5 + 21 \times 4 + 22 \times 1}{2+3+5+4+1}$

= 19.93 minutes

Normal time (NT) = CT × PR

= 19.3 × 105%

= 20.93 min

Standard time

$$ST = \frac{NT}{1 - \%A}$$

$$= \frac{20.93}{1 - 0.10}$$

= 23.26 min

<u>Determination of standard time for the operations 2 to 4</u> ⇒

The summary of calculations of determining the standard times for operations 2 to 4 are shown in table below.

OM

Summary of calculations of Standard times of operations 2 to 4

	Work Element		
	2	3	4
%age of working	$\frac{7}{50} \times 100 = 14\%$	$\frac{21}{50} \times 100 = 42\%$	$\frac{22}{5} \times 100 = 44\%$
Actual time spent in minutes for 15 units	480×0.14 $= 67.2$	480×0.42 $= 201.6$	480×0.44 $= 211.2$
Actual time spent per unit in minutes	$\frac{67.2}{8} = 8.4$	$\frac{201.6}{8} = 25.2$	$\frac{211.2}{8} = 26.4$
Normal time in minutes	$8.4 \times 120\%$ $= 10.08\%$	$25.2 \times 125\%$ $= 31.5$	$26.4 \times 95\%$ $= 25.08$
Standard time in minutes	$\frac{10.08}{0.9} = 11.2$ $4(1-0.1)$	$\frac{31.5}{0.9} = 35$	$\frac{25.08}{0.9} = 27.87$
Standard time of the operations 2 to 4 /unit in minutes		$11.2 + 35$ $+ 27.87$ $= 74.07$	

∴ The standard time of the job per unit

= Standard time of operation 1

+ Standard time of operations from 2 to 4

= 23.26 + 74.07 = 97.33 minutes.

Value Engineering (VE) and Value Analysis (VA)

Value

In POM, **Value** is defined as:

Value = Function/Cost

Value can be increased by:

- Improving function
- Reducing cost
- Improving function at the same cost

Value Engineering (VE)

Value Engineering is a **systematic and creative technique** applied **during the design stage** of a product or process to improve value by achieving the **required functions at the lowest life-cycle cost**, without affecting quality, reliability, or performance.

Key focus: *Pre-production stage*

Procedure of Value Engineering

Step 1: Information Phase

- Study product, drawings, specifications
- Identify functions and costs

Step 2: Function Analysis

- Identify **basic and secondary functions**
- Use **verb–noun** format (e.g., *support load*)

Step 3: Creative Phase

- Brainstorm alternative ways to perform functions
- No criticism during idea generation

Step 4: Evaluation Phase

- Evaluate ideas based on:
  - Cost
  - Feasibility
  - Performance

Step 5: Development Phase

- Develop selected ideas into workable solutions
- Cost–benefit analysis

Step 6: Implementation Phase

- Apply approved alternatives
- Monitor performance

Benefits of Value Engineering

- Reduction in product cost
- Improved product quality and reliability
- Better material utilization

- Enhanced competitiveness
- Encourages innovation
- Reduced manufacturing time

Value Analysis (VA)

Value Analysis is the application of **value engineering techniques to existing products or processes** to improve value by eliminating **unnecessary costs** without reducing functional performance.

Key focus: *Post-production / existing products*

Procedure of Value Analysis

The procedure is **similar to VE**, but applied to products already in use.

Step 1: Selection of Product

- Choose high-cost or high-volume products

Step 2: Information Gathering

- Collect data on materials, processes, and costs

Step 3: Function Analysis

- Identify essential and non-essential functions

Step 4: Creative Alternatives

- Generate cost-effective alternatives

Step 5: Evaluation

- Compare alternatives for cost, quality, and feasibility

Step 6: Implementation

- Introduce improvements and monitor savings

Benefits of Value Analysis

- Cost reduction in existing products
- Improved profitability

- Elimination of unnecessary features
- Better standardization
- Increased customer satisfaction

Difference Between VE and VA

Aspect	**Value Engineering**	**Value Analysis**
Stage	Design stage	After production
Product status	New product	Existing product
Cost reduction potential	High	Moderate
Design flexibility	High	Limited
Objective	Prevent unnecessary cost	Eliminate unnecessary cost

Applications

- Product design
- Manufacturing processes
- Packaging
- Construction projects

- Service industries

Value Engineering and **Value Analysis** are powerful cost-reduction techniques that improve value by focusing on **functions rather than components**. VE prevents unnecessary costs during design, while VA eliminates unnecessary costs in existing products, helping organizations achieve **cost leadership and customer satisfaction**.

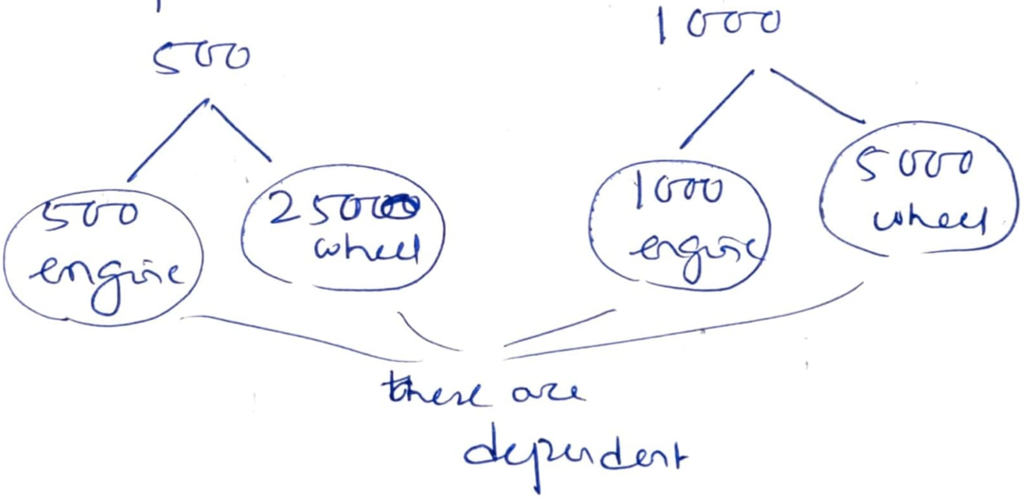
OM

Material Requirement Planning (MRP)

Material reqirment planning (MRP) is a computerized system used in manufacturing to ensure that the right materials are available at the right time for production while keeping inventory levels as low as possible.

→ ~~P~~ Used for or applicable for Dependent Demand Item

ex :- 500 car manufacturing in a year. So car is not the dependent item but the parts, small small items are the dependent item.



OM

MRP is a planning and control system that determines:

- What materials are needed.
- How much is needed
- When it is needed.

3 parts of MRP or Input to MRP :

(1) Master production schedule (MPS)

What to produce & when.

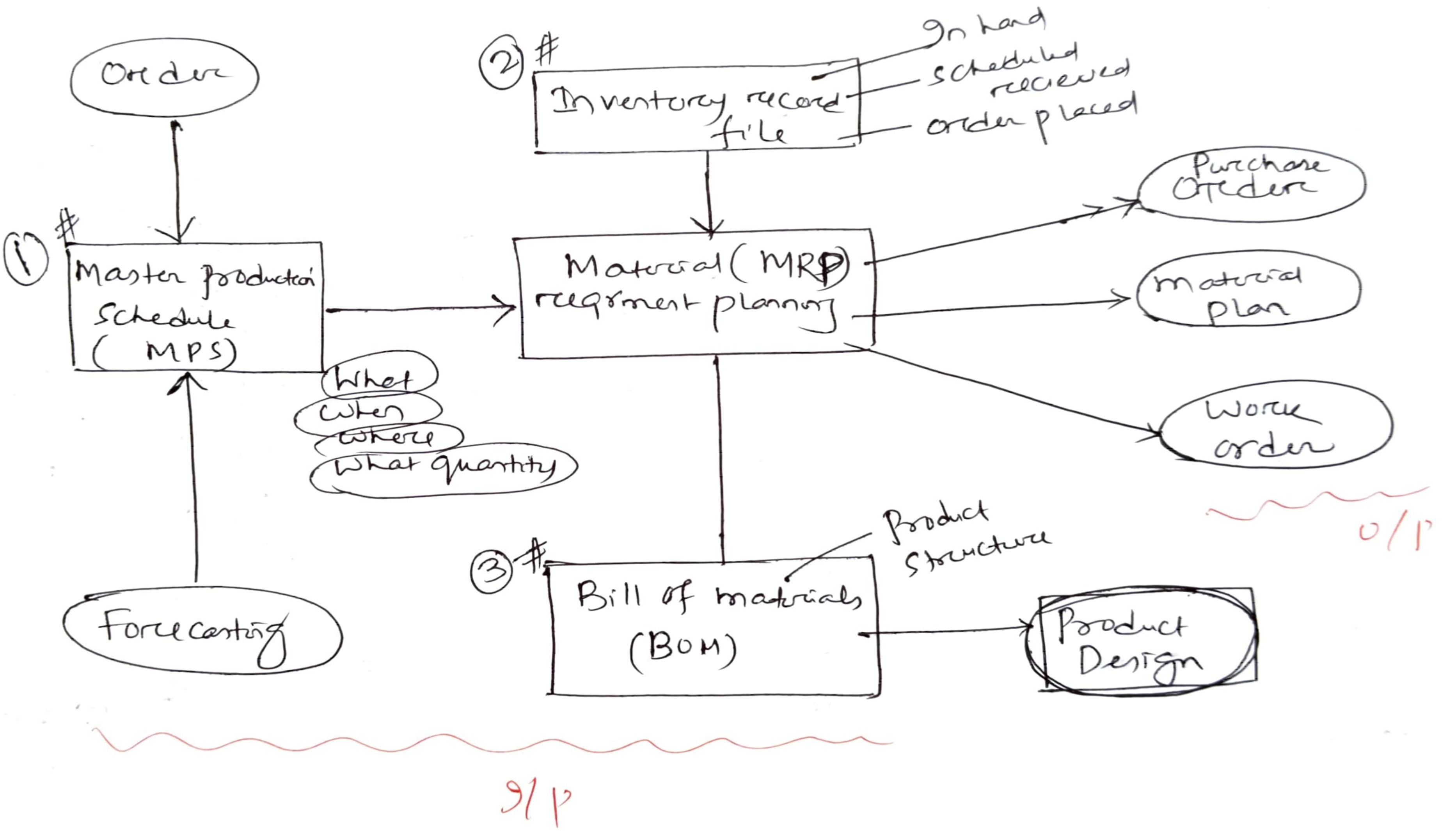
(2) Inventory Record file

Current inventory & Outstanding orders.

(3) Bill of Materials (BOM)

List of all components & materials required

OM


Order
① # Master production Schedule (MPS)
What
when
where
What quantity
Forecasting
② # Inventory record file
On hand
scheduled recieved
order placed
Material (MRP) requirement planning
③ # Bill of materials (BOM)
Product Structure
Product Design
Purchase Order
material plan
Work order
o/p
i/p

OH

MPS (master production schedule) ⇒

Final Product	Schedule 1 month	2	3	4	5
Car 1					
Car 2					
Car 3					

What
when
where
what quantity

Inventory record file

Net reqrment

= Gross reqrment − Inhand − transportation

ex ÷ 1000 engine reqrment

= 1000 − 300 − 600

= 100 is net reqrmt

Bill of material (BOM)

Product structure

ex ÷ To make final product following items are reqr.

ie By G & C → E will make

By F & G → C will make

A product →

reqr

B ⇒ 1

C ⇒ 2

D ⇒ 1

E → 1

F ⇒ 1

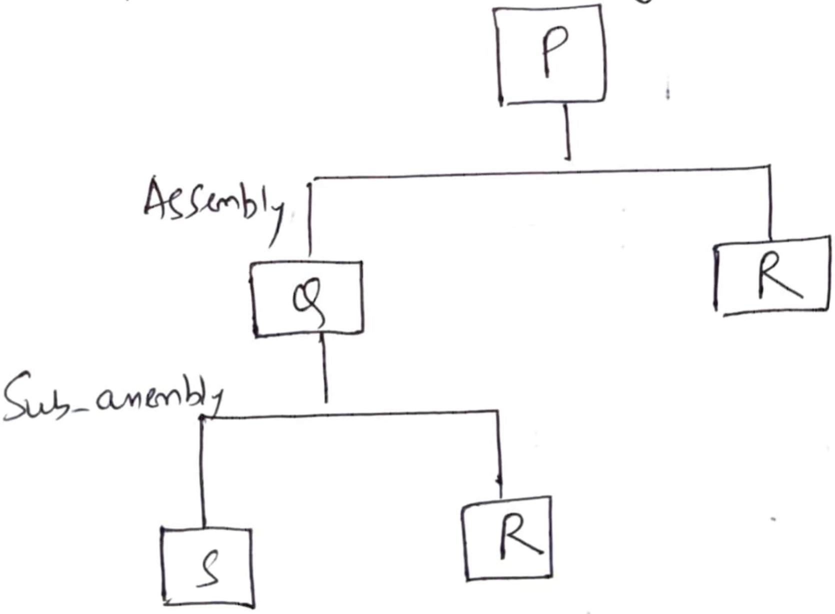
G ⇒ 2

BOM is applicable only for Dependent item.

For dependent item only, we can do material requirement planning.

For Final product, we (independent) can only do forecasting for estimation.

Q- The product structure of an assembly 'P' is shown in the figure



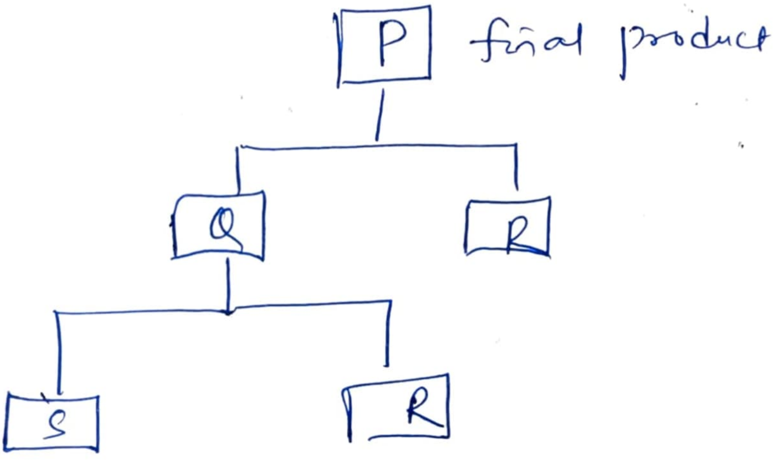
OM

Estimated demand for end product 'P' is shown as follows;

Week	Demand
1	1000
2	1000
3	1000
4	1000
5	1200
6	1200

Ignore lead times for assembly & sub-assembly. Production capacity (per week) for component R is the bottleneck operation. Starting with zero inventory, the smallest capacity that will ensure a feasible production plan upto week 6 is:

(A) 1000 (B) 1200 (C) 2200 (D) 2400



P ~~teo~~ produce the final product

Q ⇒ 1

R ⇒ 2

S ⇒ 1

R ⇒ minm reqrmnt ? that will ensure 6 week prodn.

Total no. of product in 6 week

= 1000 + 1000 + 1000 + 1000 + 1200 + 1200.

= 6400 P Product

To make 'p' reqrment of component

R = 2 × 6400 $\quad 1P \xrightarrow{\text{reqr}} 2R$

= 12800 component reqr for six week

i.e 'R' for 1 week → 12800/6

= 2133.33 minm this reqr.

i.e Answer = 2200 unit

Answer near to that

OM

Week 1	Demand	R reqirment ('2 for 1 P)	Available Inventory	
1	1000	2000	2133.33	133
2	1000	2000	"	
3	1000	2000	"	
4	1000	2000	,,	
5	1200	2400	"	2133
6	1200	2400	"	

If 'Q' is asked

then reqirment of Q

$Q \Rightarrow 6400$

for min reqirment in one week

$$\frac{6400}{6} = 1066.66$$

OM

⑨

Q.48

Capacities of production of an item over 3 Consecutive months in regular time are 100, 100 and 80 and in overtime are 20, 20, & 40. The demand over those 3 months are 90, 130, 110. The Cost of production in regular time and overtime are respectively Rs 20 per item & Rs 24 per item. Inventory Carrying Cost is Rs 2 per item month. The levels of Starting and final inventory are nil. Backorder is not permitted. For minm Cost of plan, the level of planned production in overtime in the 3rd month is ______

(A) 40 (B) 30 (C) 20 (D) 0

OM

Plant
any product × Periods
Product

Product	Regular Prodⁿ	Overtime	Demand
month 1	100	20	90
2	100	20	130
3	80	40	110

Start Inventory = 0

End/final Inventory = 0

1st month

Inventory	D	Regular Prodⁿ	Left
0	90	100	⇒ 10 kept as inventory

(as demand is 90, prodⁿ 100, no need of overtime prodⁿ)

2nd month

Inventory	D	Regular Prodⁿ	Overtime (reqr here)
	130	100 +10 (Left earlier one)	20

= 130

3rd month

D	Regular Prodn	Overtime (40 is thr)
110	80	30

30 we will use as we cannot kept the inventory

80 + 30
= 110

Inventory = 0

So For the level of planned production is overtime in the 3rd month is 30

option (B) Ans

Q -

Materials Requirement Planning (MRP-I)

MRP-I is a **computer-based information system** used to determine:

- **What materials** are required
- **How much** is required
- **When** they are required

It ensures **right material, right quantity, right time** for production.

Objectives of MRP-I

- Minimize inventory levels
- Avoid production delays
- Improve customer service

- Optimize material planning

Logic of MRP-I

The logic of MRP-I works on **backward scheduling**.

Steps:

1. Start with **Master Production Schedule (MPS)**
2. Explode product structure using **Bill of Materials (BOM)**
3. Check **inventory status**
4. Offset requirements using **lead time**
5. Generate:
    - Planned order releases

    - Planned order receipts

Structure of MRP-I

Inputs:

1. **Master Production Schedule (MPS)**
2. **Bill of Materials (BOM)**
3. **Inventory Records File**

Processing:

- BOM explosion
- Netting
- Lot sizing

- Time phasing

Outputs:

- Planned order releases
- Purchase orders
- Rescheduling notices
- Inventory reports

MRP-I Flow Diagram (Textual)

MPS → BOM → Inventory Status → MRP Processor → Planned Orders

Manufacturing Resource Planning (MRP-II)

MRP-II is an **extension of MRP-I** that integrates **all manufacturing resources**, including:

- Materials
- Machines
- Manpower
- Finance

Objectives of MRP-II

- Integrate business planning with production
- Improve capacity utilization
- Enhance coordination across departments

Logic of MRP-II

- Begins with **business planning**
- Converts business plan into:
    - Sales plan
    - Production plan
    - Capacity plan
- Uses **feedback loops** to adjust plans

Structure of MRP-II

Core Modules:

1. Business Planning

2. Sales & Operations Planning (S&OP)
3. Master Production Scheduling
4. Material Requirements Planning
5. Capacity Requirements Planning (CRP)
6. Shop Floor Control
7. Purchasing
8. Financial Interface

Difference Between MRP-I and MRP-II

Aspect	MRP-I	MRP-II
Focus	Materials	All resources

Scope	Production	Entire organization
Capacity planning	Not included	Included
Financial link	No	Yes
Feedback	Limited	Closed-loop

Theory of Constraints (TOC)

TOC is a management philosophy developed by **Eliyahu M. Goldratt**, stating that:

“Every system has at least one constraint that limits its performance.”

Goal of TOC

Maximize **Throughput** while minimizing:

- Inventory
- Operating expense

Types of Constraints

- Physical (machine, labor)
- Policy (rules, procedures)
- Market (demand)
- Supply (materials)
- Behavioral (people)

Five Focusing Steps of TOC

1. Identify the constraint

2. Exploit the constraint
3. Subordinate everything else
4. Elevate the constraint
5. Repeat (continuous improvement)

TOC Performance Measures

- **Throughput (T)**
- **Inventory (I)**
- **Operating Expense (OE)**

Critical Chain Project Management (CCPM)

CCPM is a **TOC-based project management technique** that focuses on:

- Resource constraints
- Eliminating multitasking
- Buffer management

Logic of CCPM

- Traditional CPM ignores resource constraints
- CCPM identifies the **critical chain** (longest chain considering resource dependencies)
- Safety times removed from individual tasks
- Aggregated into **buffers**

Structure of CCPM

Key Elements:

1. **Critical Chain**
2. **Project Buffer**
3. **Feeding Buffers**
4. **Resource Buffers**

Buffer Management

- Monitors project progress
- Controls uncertainty
- Protects delivery date

Benefits of CCPM

- Reduced project duration
- Better on-time delivery
- Less multitasking
- Improved resource utilization

TOC vs Traditional Project Management

Aspect	CPM/PERT	CCPM
Focus	Task sequence	Resource constraints
Safety time	In each task	Centralized buffers
Multitasking	Common	Eliminated
Control	Activity-based	Buffer-based

ASSEMBLY LINE BALANCING

In a **production or assembly line**, the total work required to manufacture a product is divided into several **small tasks**. These tasks are assigned to **different workstations** arranged in a sequence. If the tasks are not properly distributed, some stations may have **more work** (bottleneck) while others remain **idle**. To avoid this imbalance, **line balancing** is used.

An **assembly line** is a manufacturing process in which a product moves along a conveyor or line through a sequence of workstations. Each workstation performs a specific task, and the product becomes more complete as it moves down the line. However, if tasks are not properly distributed among the stations, **some workers may be idle while others are overloaded**. This problem is solved by **Assembly Line Balancing (ALB)**.

Definition

Assembly Line Balancing is the process of **assigning individual tasks to workstations so that all workstations have nearly equal workloads**, and the total idle time of the line is minimized. It aims to balance the **work content** at each station to achieve a **smooth, continuous flow of production**.

Objectives of Assembly Line Balancing

- To **minimize idle time** and **maximize productivity**.
- To **achieve the desired rate of output**.
- To ensure a **smooth flow of materials** through the production system.
- To **reduce bottlenecks** and waiting time between stations.
- To make **optimum use of manpower and machines**.
- To **minimize production cost** and **increase efficiency**

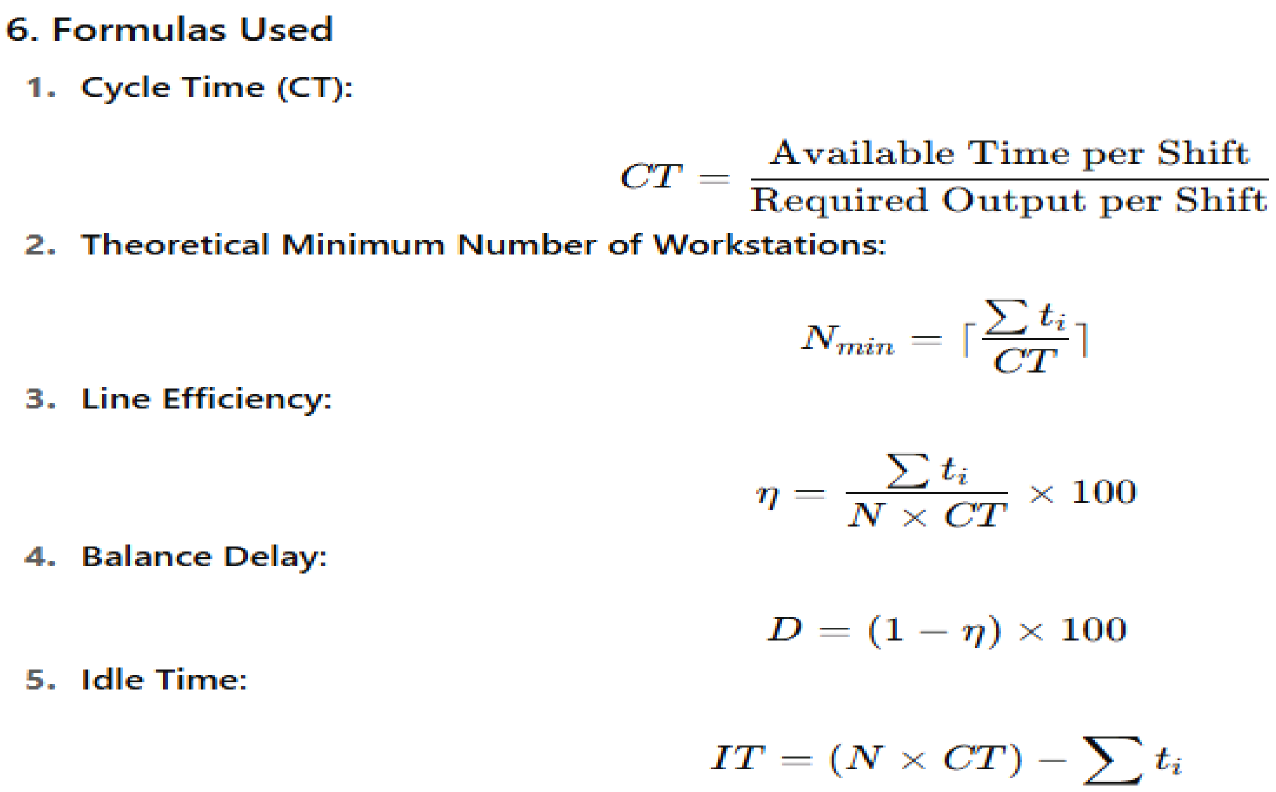
Importance / Need

- Increases **line efficiency** and **production rate**.
- Ensures **uniform workload** distribution.
- Reduces **work-in-progress (WIP)** inventory.
- Improves **quality and scheduling accuracy**.
- Facilitates **better supervision and control**.
- Essential for **mass production systems** (automobiles, electronics, etc.).

Basic Terms

Term	Description
Work Element / Task	A specific operation performed at one workstation.
Workstation	A physical location where tasks are carried out.
Cycle Time (CT) or (T_C**)> or =** T_{si} **max**	The time interval between completion of two consecutive products.
Task Time (T_i**)**	Time required to complete a specific task.
Total Work Content ($T.W.C= \Sigma T_{si}$**)**	Total time to assemble one complete product.
Precedence Relationship	Logical order in which tasks must be performed.

Term	Description
Idle Time	Time when a workstation remains unutilized.
Line Efficiency (Line η)	Ratio of productive time to total available time.
Balance Delay (B.D)	Percentage of time lost due to imbalance.



6. Formulas Used

1. **Cycle Time (CT):**

$$CT = \frac{\text{Available Time per Shift}}{\text{Required Output per Shift}}$$

2. **Theoretical Minimum Number of Workstations:**

$$N_{min} = \lceil \frac{\sum t_i}{CT} \rceil$$

3. **Line Efficiency:**

$$\eta = \frac{\sum t_i}{N \times CT} \times 100$$

4. **Balance Delay:**

$$D = (1 - \eta) \times 100$$

5. **Idle Time:**

$$IT = (N \times CT) - \sum t_i$$

Methods of Assembly Line Balancing

1. **Largest Candidate Rule (LCR):**
   - List tasks in descending order of time.
   - Assign tasks to stations until the cycle time limit is reached.
2. **Ranked Positional Weight (RPW) Method:**
   - Compute the positional weight of each task (its own time + all following tasks).
   - Assign tasks based on rank and precedence.
3. **Kilbridge and Wester Method:**
   - Use a precedence diagram divided into columns and assign tasks from left to right.
4. **Heuristic and Computerized Methods:**

  - Use software algorithms for complex systems (e.g., COMSOAL, genetic algorithms)

Steps in Assembly Line Balancing

1. Identify all **tasks and their times**.
2. Establish **precedence relationships** among tasks.
3. Draw a **precedence diagram**.
4. Calculate **cycle time (T_c)** and **N_{min}**.
5. Assign tasks to workstations using a suitable method.
6. Ensure each station's total time ≤ CT.
7. Compute **line efficiency**, **balance delay**, and **idle time**.

8. Rearrange tasks if necessary to improve balance.

Advantages

- Increases **production rate and throughput**.
- Reduces **idle time and bottlenecks**.
- Improves **equipment and labor utilization**.
- Reduces **cost and WIP**.
- Enables **steady, continuous production**.
- Simplifies **management and control**.

Limitations

- Perfect balance is often **difficult to achieve**.
- **Task time variation** can disturb balance.
- **Product design changes** require rebalance.
- Some **tasks cannot be divided** or shared.
- Requires **accurate data** on task times and sequence.

Applications

- Automobile assembly lines (cars, bikes).

- Electronics manufacturing (TVs, mobile phones).
- Consumer goods (washing machines, refrigerators).
- Food packaging and bottling plants.
- Any **mass production system** with sequential operations.

HEURISTICS IN ASSEMBLY LINE BALANCING

Introduction

In assembly line balancing, we aim to distribute tasks among workstations so that each workstation has (almost) equal total task time without violating **precedence constraints** and **cycle time**.

However, for real-world problems with many tasks, finding the *perfect or optimal* balance is **very complex** (NP-hard problem). Hence, industries use **heuristic methods** — practical rules or algorithms that give *good, near-optimal solutions quickly*.

Definition

A **heuristic** is a *rule-of-thumb method* or *approximation technique* used to find a **feasible and reasonably good solution** to a problem, especially when an exact solution is too time-consuming or difficult to compute.

In the context of **assembly line balancing**, heuristic methods are used to:

- Assign tasks to workstations efficiently.
- Achieve high line efficiency.

- Satisfy all precedence and time constraints.

Need for Heuristics

- Exact optimization requires **mathematical models** (like integer programming), which are **time-consuming** for large lines.
- Heuristics provide **fast and practical** results.
- Easy to **implement manually or through simple computer programs**.
- Allow **adjustments** when product designs or demands change.

Objectives of Heuristic Line Balancing

- To **minimize the number of workstations**.
- To **maximize line efficiency**.

- To **reduce idle time and balance delay**.
- To **maintain precedence relationships** among tasks.

Common Heuristic Methods

Below are the main heuristics widely used in industry and academic practice:

(a) Largest Candidate Rule (LCR)

Idea: Assign the longest task first to fill the workstation up to the cycle time.
Steps:

1. List all tasks in **descending order** of task time.
2. Assign tasks one by one to a workstation without exceeding **cycle time** and while respecting **precedence**.

3. Move to the next workstation and repeat.

✓ *Simple and fast*

✗ *May not always give the best solution*

(b) Ranked Positional Weight (RPW) Method

Idea: Tasks that influence many other tasks (downstream) are given higher priority.

Steps:

1. Compute **positional weight** for each task:

   PWi = t_i + sum of times of all successor tasks.

2. Rank tasks in descending order of PW.

3. Assign tasks to workstations based on precedence and cycle time.

✓ *Considers overall influence of tasks*
✗ *Requires precedence diagram*

(c) Kilbridge and Wester Method

Idea: Uses a **column-based approach** on the precedence diagram.

Steps:

1. Divide tasks into columns based on their position in the precedence diagram.
2. Start from the first column and assign tasks to stations without exceeding CT.
3. Move to next column and repeat.

✓ *Visually clear and easy to use*

✗ *Less accurate for complex diagrams*

(d) COMSOAL (Computer Method of Sequencing Operations for Assembly Lines)

Idea: Randomized heuristic; computer assigns tasks in different random feasible sequences to find a good balance.

Steps:

1. Identify all possible tasks that can be assigned next.
2. Randomly select one and continue until all tasks are assigned.
3. Repeat several times and select the best (lowest number of stations or highest efficiency).

✓ *Good for large problems*
✗ *Requires computer and multiple iterations*

(e) Incremental or Probabilistic Heuristics

These use **improvement-based approaches**, like:

- **Genetic algorithms**
- **Simulated annealing**
- **Tabu search**

These are **modern metaheuristic methods**, used for large-scale assembly line balancing.

Evaluation Parameters

After applying a heuristic, solutions are evaluated using:

- **Line efficiency (η)**
- **Balance delay (D)**
- **Number of stations (N)**
- **Idle time per cycle**

Best heuristic = one that gives the **highest efficiency** and **minimum stations** while satisfying all constraints.

Advantages of Heuristic Methods

✓ Fast and easy to use

✓ Provide good (near-optimal) solutions

✓ Flexible and adaptable

✓ Require less computational effort

✓ Can be applied manually or using simple software

Limitations

✗ Do not always give the *best* (optimal) solution

✗ Sensitive to task order and precedence structure

✗ Some heuristics require trial and error

✗ Effectiveness depends on problem type

Conclusion

Heuristic methods are **practical and efficient tools** for solving assembly line balancing problems.
They provide **quick, feasible, and near-optimal solutions** suitable for real-world manufacturing systems where time and flexibility are critical.

In modern industries, heuristics are often combined with **computerized optimization** and **metaheuristic algorithms** for better results.

OM

①

ASSEMBLY LINE BALANCING

Assembly line balancing is the process of arranging tasks on an assembly line so that each workstation has a roughly equal amount of work & the overall workflow is smooth & efficient.

Defination ⇒

Assembly line balancing is the technique of distributing tasks among various work stations so that each workstation completes its tasks within the same cycle time and no workstation is overburdened / underutilized.

Objective ÷

≫ To minimize the idle time of workers and machines

≫ To maximize O/P (productivity)

≫ To reduce production time (cycle time)

≫ To reduce Labor Cost

≫ To avoid bottlenecks & delays.

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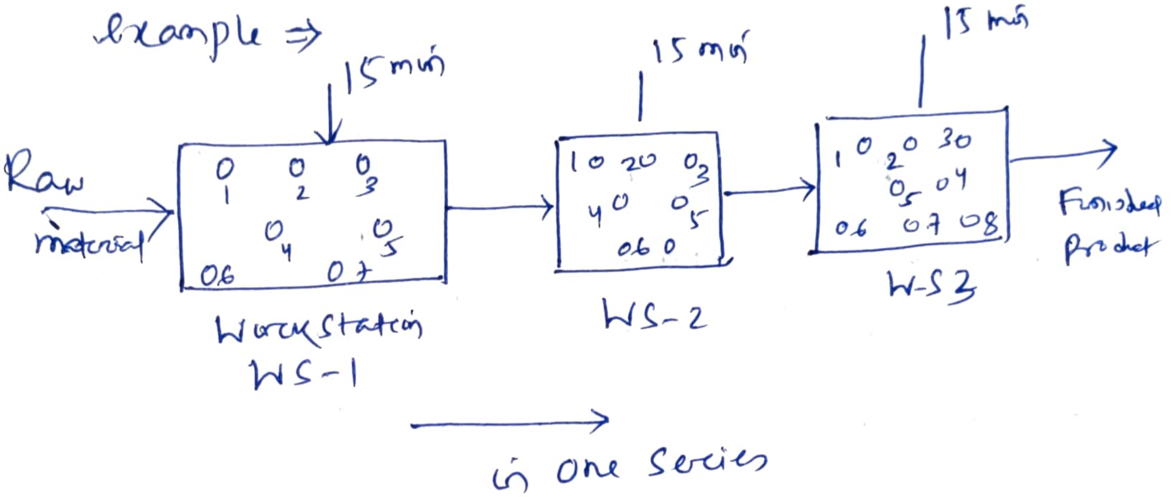
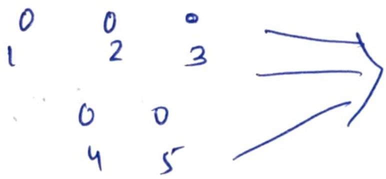
Advantage ⇒

- ≫ Reduce work handling.
- ≫ Uniform production rate.
- ≫ Better use of m/c & manpower
- ≫ Less Congestion.

example ⇒



Sequence we are finding from Network flow diagram



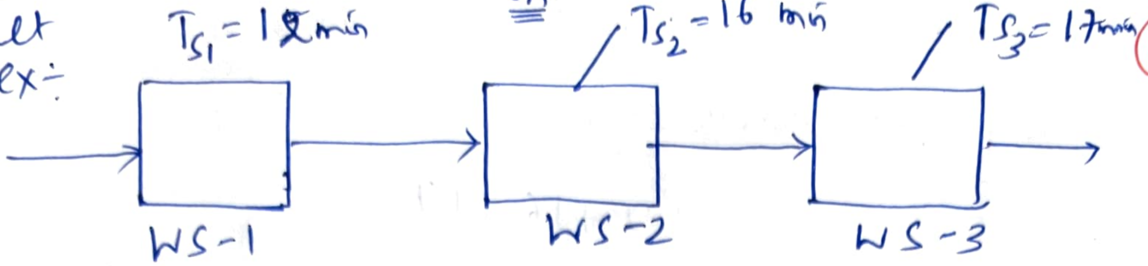
Element → Task time (T_i)

$$\sum T_i = T_{s_i}$$

⇓

Work station time

Let ex:-



Cycle time = 17 min

max^m work station time = (T_c) cycle time.

As in WS-1, $T_{s_1} = 12$ min

and if we give cycle cycle to 12 min then WS-2 & WS-3, work will be incomplete

So cycle time = 17 min we have to take. & In that case in WS-1,

idle time = 17 - 12 = 5 min ; which are have to assign the work to WS-1 in such a way that minimize so that we can minimize the idle time of workers as well as m/cs.

Similly $T_{s_2} = 16$ min

Idle time = 17 - 16 = 1 min of WS_2 idle time.

$$\boxed{T_c \geq T_{s_i}(max)}$$

i.e max^m work station time

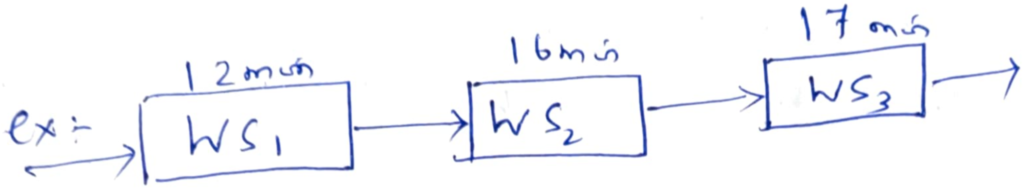
Total work content ⇒ or total job time

12+16+17

i.e total job time = $\sum T_{s_i}$

or total work content (T.W.C)

ex:-



Cycle time T_c = 17 mins (i.e. maxm workstation time)

Available time at work station

= n × T_c

= 3 × 17 = 51 mins

n = No. of work stations.

But Total work content or actual job time (T.W.C)

$= \sum T_{s_i}$

= 12+16+17 = 45 mins

∴ Line efficiency (Line η) = $\frac{45}{51}$

OM

$$\Rightarrow \boxed{\text{Line } \eta = \frac{T.W.C}{n\,T_c} = \frac{\Sigma T_{si}}{n\,T_c}}$$

as % then multiply 100

$$\boxed{\text{Idle time} = n\,T_c - T.W.C}$$

$$\text{Balance Delay (B.D)} = \frac{\text{Idle time}}{\text{Total time}}$$

$$= \frac{n\,T_c - TWC}{n\,T_c}$$

$$= \frac{n\,T_c - \Sigma T_{si}}{n\,T_c}$$

OM

#

(I) Element ⇒ Job → T_i = Task time

(II) Work Station time ⇒ T_{si}

Total Work Station time = $\sum T_i$
at a particular work station

(III) cycle time = maxm work Station time

$(T_c) \geq T_{si}$ max

(IV) Total work Content = $\sum T_{si}$

Total Job flow time

(T.W.C)

(V) Total available time at work station = $n \times T_c$

n = No. of work station

(VI) Idle time = $nT_c - T.W.C$

$= nT_c - \sum T_{si}$

(VII) Balance delay = $\frac{nT_c - T.W.C}{nT_c} \times 100$

(in %age)

~~(VIII)~~ $= \frac{nT_c - \sum T_{si}}{nT_c} \times 100$

(VIII) Efficiency $\eta = (1 - B.D)$ %

Smoothness Index ⇒

$$\boxed{S.I = \sqrt{\sum_{i=1}^{n} (\text{Maxm W.S. Time} - \text{Station time})}}$$

signifies Load distribution on work station.

If S.I ↑ Load not properly distributed

S.I ↓ Load properly distributed

Minimum No. of work station ⇒

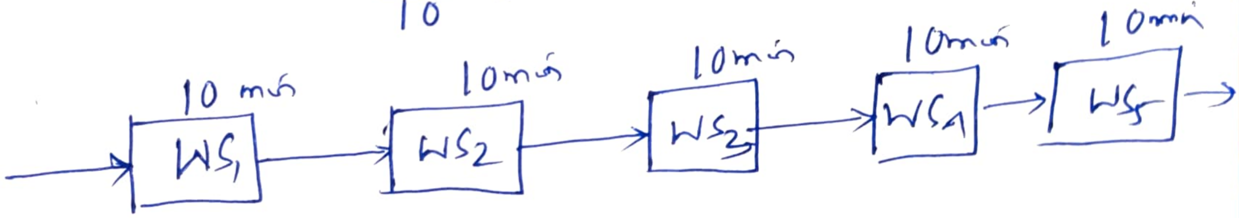
$$\boxed{n_{(\min)} = \frac{TWC}{T_c}}$$

TWC = Total work content or total job flow time

T_c = maxm work station time

ex:- TWC = 50   Let $T_c = 10$

∴ $\frac{50}{10} = 5$ min work station.



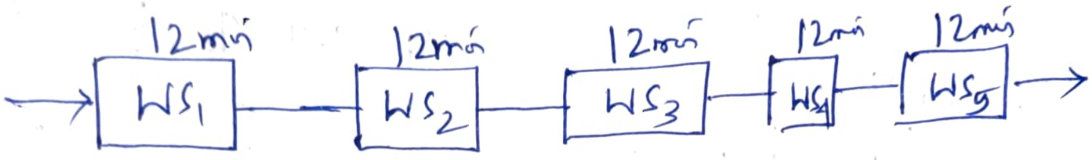
OM

Q. 43

Let $\sum T_{s_i} = 60$ min

cycle time = 12 mins

∴ Minm work station reqr = $\frac{60}{12} = 5$



Let $\sum T_{s_i} = 65$ min

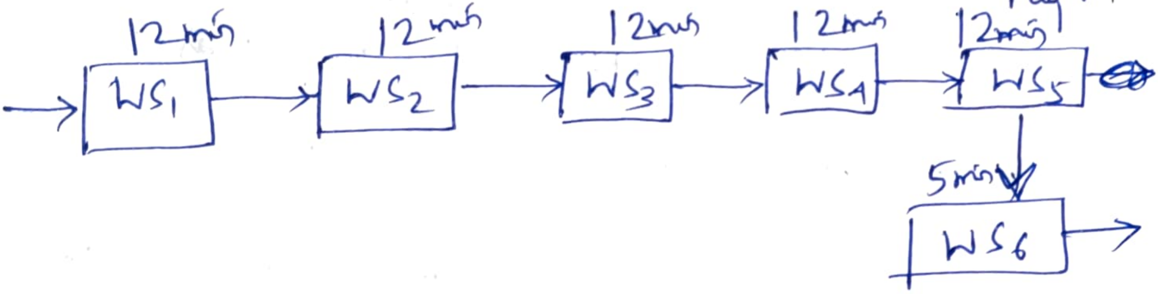
cycle time = 12 min

∴ Minm work station reqr = $\frac{65}{12}$

= 5.41 no.

As Then minm is 5.41

∴ We have to take 6 work station reqr.



Q. 43 The table gives details of an assembly line

Work station	I	II	III	IV	V	VI
Total task time at the work station (in minutes)	7	9	7	10	9	6

What is the line efficiency of the assembly line

(A) 70 %.

(B) 75 %.

[✓ (C) 80 %.]

(D) 85 %.

T_{S_i}

~~≈ Σ Q~~ ~~all small~~ ~~small jobs~~

$\sum T_i = T_{S_i}$

↳ element or job.

$$\text{line } \eta = \frac{T.W.C}{n\,T_C} \times 100$$

$n = 6$, $T.W.C = 7 + 9 + 7 + 10 + 9 + 6$
$= 48$

cycle time $T_C = 10$ $\quad T_C \geq \text{max}^m \text{ of } T_{S_i}$

$$\therefore \text{line } \eta = \frac{48}{6 \times 10} \times 100$$

$$= \frac{48}{60} \times 100$$

$= 80\%$ option (C) Ans

Q. 44 In an assembly line, for assembling toys, five workers are assigned which take times of 10, 8, 6, 9, 10 minutes respectively. The balance delay for line is

(A) 43.3% (B) 14.8% (C) 14.0% (D) 16.3%

n = no. of work stations = 5

$T.W.C = 10 + 8 + 6 + 9 + 10 = 43$

$T_c = 10$ $\qquad T_c \geqslant TS_i$

$$\text{Balance delay (B.D)} = \frac{nT_c - TWC}{nT_c} \times 100$$

i.e nothing but $\frac{\text{Idle time}}{nT_c} \times 100$

$$= \frac{5 \times 10 - 43}{5 \times 10} \times 100$$

= ~~×100~~ $\frac{7}{50} \times 100$

= 14 %

Q.45 An electronic equipment manufacture has decided to add a component sub-assembly operation, that has produce 80 units during a regular 8-hour shift. This operation consists of three activities as below,

Activity standard time (min):

M. Mechanical assembly 12

E. Electric wiring : 16

T. Test : 3

The line balancing the no. of work station reqr for the activity M, E & T would respectively:

(A) 2, 3, 1 (B) 3, 2, 1 (C) 2, 4, 2 (D) 2, 2; 1, 3

80 units $\xrightarrow{\text{to Produce}}$ in 8 hour shift.

We know

Minimum No. of work station

$$= \frac{TWC}{T_c}$$

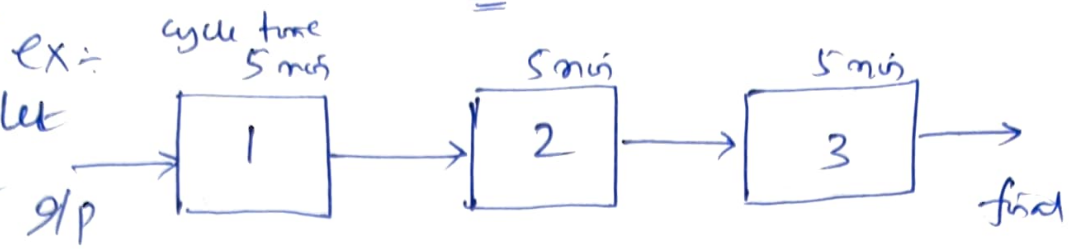
80 units in 8 hours

$= 8 \times 60$ min

OM

Imp

[ex:- let



then time betn two consecutive product
= 5 min

i.e One product is produced in 5 min also we can say.]

Imp

So 80 units in 8 hours.

$$1 \text{ unit} \rightarrow \frac{8 \times 60 \text{ min}}{80} = 6 \text{ min}$$

i.e this is called as

time betn two consecutive product (or sucessive) (order)

i.e nothing but cycle time ..

$$\therefore T_c = 6 \text{ min}$$

Sub-assemblyes)

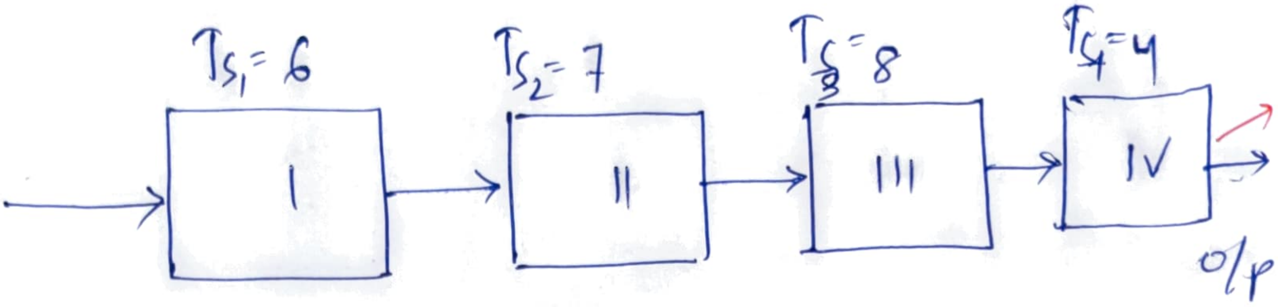
$$n_1 = \frac{TWC}{T_c} = \frac{12}{6} \doteqdot 2$$

$$n_2 = \frac{TWC}{T_c} = \frac{16}{6} = 2.66 \doteqdot 3$$

$$n_3 = \frac{TWC}{T_c} = \frac{3}{6} = 0.5 = 1$$

Ans:- (2, 3, 1) option (a)

OM



$$T_c = \text{maxm of } T_{s_i}$$

$$= 8$$

i.e nothing but after 8 min we will get the finished product.

Q ⇒ Draw the precedence diagram and determine balance delay, line efficiency and smoothness - index taking cycle time as 1 min.

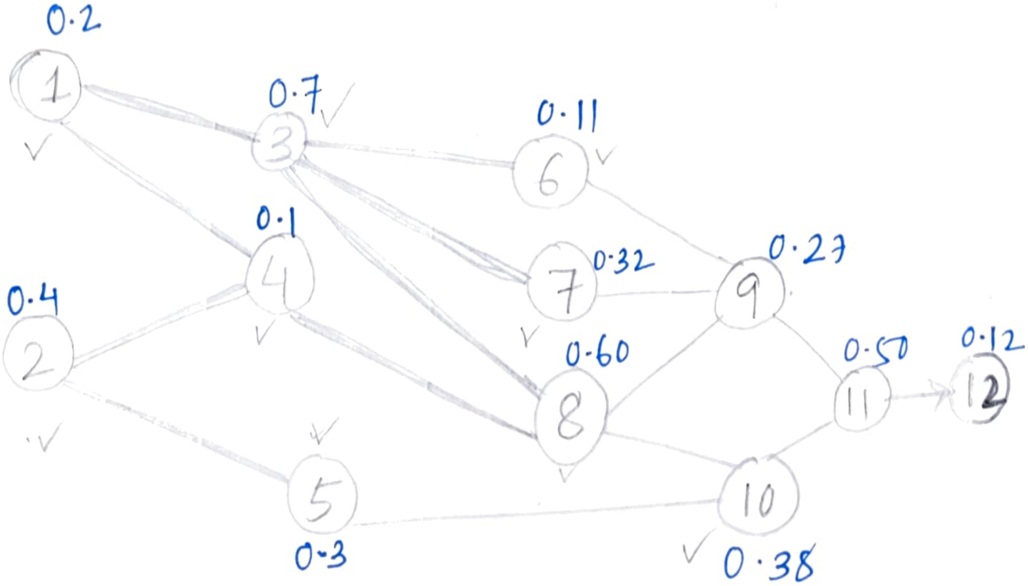
Element	Time(min)	Precedence
1	0.2	—
2	0.4	—
3	0.7	1
4	0.1	1, 2
5	0.3	2
6	0.11	3
7	0.32	3
8	0.60	3, 4
9	0.27	6, 7, 8
10	0.38	5, 8
11	0.50	9, 10
12	0.12	11

Solve by
→ Largest Candidate rule

Step - I

OM

Draw the precedence diagram (AON diagram) (Activity on Node diagram)



Step - II Arrange all the elements in the decreasing order of task time.

Step - III

classify the elements into different work station such that cycle time $\geq (T_s)_{max}$ by following the precedence relation.

Element	Time	Precedence
3	0.7.	1
8	0.6	3,4
11	0.5	9,10
2	0.4	—
10	0.38	5, 8
7	0.32	3
5	0.30	2
9	0.27	6,7,8
1	0.20	—
12	0.12.	11
6	0.11	3
4	0.10	1,2

To assign an element in a workstation start from the begining of the list moving-downword, searching 1st feasible element can be placed in a worck station. A feasible element is one that satisfy precedence reqr and when that element is put in that workstation the total time of the workstation

ON

Should not exceed the cycle time.

Work Station	Element	Time	T_s	Idle time
I	2	0.4	1.0	0
	5	0.3		
	1	0.2		
	4	0.1		
II	3	0.7	0.81	0.19
	6	0.11		
III	8	0.6	0.98	0.02
	10	0.38		
IV	7	0.32	0.59	0.41
	9	0.27		
V	11	0.5	0.62	0.38
	12	0.12		

OM

Task	Procesing time (min)	predecessores
A	2	—
B	4	A
C	3	A
D	2	B
E	1	B, C
F	3	D
G	2	E & F

Choose cycle time = 7 minutes

Total work time = $2+4+3+2+1+3+2$

= 17 minutes

(C.T.) or T_c = ~~1~~7 minutes.

∴ Minm no. of (theoritical) stations

$$= \frac{\text{Total time}}{\text{cycle time}} = \frac{17}{7}$$

$= 2.4286 \ldots$

= 3 stations.

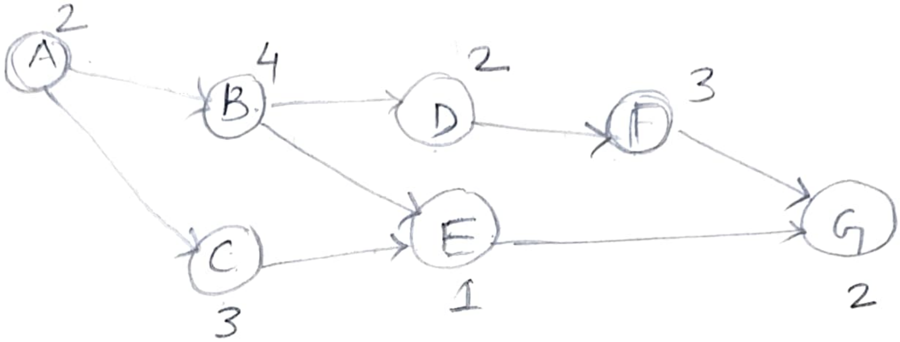
Step - I

Draw the precedence diagram.

Step - II Arrange all the elements in the decreasing order of task time i.e. in Largest Candidate rule (LCR)

procedure: At Each Station, among the available tasks (whose predecessors are already assigned) choose the Largest processing time task that fits in the remaining cycle time; repeat until no available task time fits.

OM



Task	Processing time (min)	predecessors.
~~B~~ 1st station	4	A
~~C~~ Station 2	3	A
F	3	D
~~A~~ 1st station	2	—
~~D~~ Station 2	2	B
G	2	E & F
~~E~~ Station 2	1	B, C

OM

Station 1 (Capacity = 7 min)

Not more than cycle time.

Initial Available tasks = tasks with no predecessors → A (2)

Pick Largest available = A (2).

Assign A

Remaining capacity = 7 − 2 = 5 min

Now available {B(4), C(3)}

Station 1

A → 2 min

remaining 7 − 2 = 5 min

B → 4 min

5 − 4 = 1 min remaining

Pick Largest that fits → B(4)

Assign B.

Station 1 Load = 2 + 4 = 6

∴ remaining Capacity = 7 − 6 = 1 min

After B assigned, D(2) doesn't fit (∵ remaining time = 1 min, & D having time = 2 min). C (3) also doesn't fit.

Stop Station 1.

Station 1 Assigned : A, B → Load = 6

Idle = 1

Station 2 **Capacity = 7 min**

(i) Available at start = Tasks whose predecessors are done and not yet assigned.
$\{C(3), D(2)\}$.

Pick largest available → C (3)

Assign C.

Station 2 Load = 3

remaining capacity
= 7 − 3 = 4 min.

After C done, E(1) becomes also available, since B & C are both done.

Station 2

C → 3 min

remaining 7 − 3 = 4 min

D → 2 min

remaining = 4 − 2
= 2 min

E → 1 min

remaining = 2 − 1 = 1 min
stop.

(ii) Available now = $\{D(2), E(1)\}$

Pick largest that fits → D (2)

Assign D.

∴ Station 2 Load = 3 + 2 = 5 min

remaining capacity = 7 − 5 = 2 min

After D assigned, F(3) becomes available but F(3) > remaining capacity (2).

OM

(iii) Available now {E (1)}.

Assign E(1)

Station 2 Load = 5 + 1 = 6

remaining Capacity = 7 − 6 = 1 min.

~~After G~~, After E, G not yet available.

∴ No further available task fits.

Stop station 2.

Station 2 assigned : C, D, E →

Load = 6, Idle = 1

Station 3 **Capacity = 7**

Remaining tasks available : F(3) (since D done), then after F, G(2)

(i) Assign F(3).

Station 3 Load = 3

Remaining capacity = 7 − 3 = 4

(ii) After F, G(2) becomes available. Assign G(2).

Station 3 Load = 3 + 2 = 5

Station 3

F → 3

remaining = 7 − 3 = 4

G → 2

remaining 4 − 2 = 2

No more task remain

remaining capacity = 7 − 5 = 2

No more tasks remain.

Station 3 assigned : F, G → Load = 5

Idle = 2

Summary table

Station	Tasks assigned		T_s	Idle time
1	~~A, B~~ A B	2 4	7 mins	1 mins
2	C D E	3 2 1	7 min	1 mins
3	F G	3 2	7 min	2 mins

∴ Total work time = 17 mins.

Total capacity provided

= no. of station × cycle time

= 3 × 17

= 21 mins

OM

Total idle time = 21 − 17 = 4 min

(Matches 1+1+2)

Performance metrics

No. of stations used = 3

(Equal to theoritical minimum)

Line η (E) $= \dfrac{\text{Total task time}}{\text{Available time at work station}}$

$$= \frac{T.W.C}{n T_c} \quad \text{or} \quad \frac{\Sigma T_{si}}{n T_c}$$

$$= \frac{17}{3 \times 7} = 80.95\%$$

Balance delay (BD) = 1 − E

= 1 − 80.95

= 19.05%

Smoothness (S) = Standard deviation of station Loads : Loads [6, 6, 5]

$$\sum_{i=1}^{n} (\text{max}^{m} \text{ W.S time} - \text{Station time})$$

Load $[6, 6, 5] \rightarrow$ mean $= \frac{17}{3}$

$= 5.6667$

Standard deviation

Smoothness index

$$= \sqrt{\sum_{i=1}^{n} (\text{Maxm W.S Time} - \text{Station time})}$$

$=$

$= 0.333$

Notes/ Interpretation => LCR produced a 3-Station Solution (optimal in the sense that it matches the theoritical min)

Idle times are small (1, 1, 2), giving good efficiency (~ 81%). LCR is greedy: different heuristics (ex- Kilbridge-West, Ranked positional weight) might give different station grouping - sometimes better, sometimes worse, depending on precedence structure & time.

Smoothness index (SI) in assembly line is a measure of how evenly work is distributed among work stations.

Formula for smoothness index (SI)

$$SI = \sqrt{\sum (C_{max} - T_i)^2}$$

C_{max} = Cycle time or the maxm work-station time

T_i = Total task time at work station (i)

n = No. of work stations

Step by step Calculations:

1. Find the cycle time (C_{max})

$$C = \frac{\text{Available production time per day}}{\text{Units to be produced per day}}$$

(ii) Calculate the total task time (T_i) for each workstation.

(iii) Find the deviation of each workstation from the cycle time

$$(C_{max} - T_i)$$

(iv) Square each deviation

$$(C_{max} - T_i)^2$$

(v) Sum all squared deviations & take the square root.

$$SI = \sqrt{\sum (C_{max} - T_i)^2}$$

* A Lower SI means better line balance (work evenly distributed)

* A higher SI means more imbalance

Example:

Work station	Task time (T_i)
1	45 sec
2	40 sec
3	50 sec

∴ Cycle time $C_{max} = 50$ sec

$$S.I = \sqrt{(50-45)^2 + (50-40)^2 + (50-50)^2}$$

$$\Rightarrow S.I = \sqrt{5^2 + 10^2 + 0^2}$$

$$= \sqrt{125}$$

Smoothness index = 11.18 sec.

S.I as %age of cycle time

$$\frac{S.I}{C} = \frac{11.18}{50} = 22.36\%$$

Smoothness Index Numerical

The smoothness index is calculated numerically to measure the workload balance across stations. Here's a simple example calculation:

Suppose an assembly line has 4 workstations with the following workloads (in minutes):

- Station 1: 5 minutes
- Station 2: 7 minutes
- Station 3: 6 minutes
- Station 4: 4 minutes

Assume the cycle time C is the maximum station time, which is 7 minutes.

Using the smoothness index formula:

$$SI = \sqrt{(7-5)^2 + (7-7)^2 + (7-6)^2 + (7-4)^2}$$

Calculating each term:

- $(7-5)^2 = 2^2 = 4$
- $(7-7)^2 = 0^2 = 0$
- $(7-6)^2 = 1^2 = 1$
- $(7-4)^2 = 3^2 = 9$

Sum:

$$4 + 0 + 1 + 9 = 14$$

Square root:

$$SI = \sqrt{14} \approx 3.74$$

So, the smoothness index of this line is approximately 3.74. A smaller number would indicate a more balanced line, while a larger number indicates more imbalance.

This numerical example shows how the formula quantifies workload distribution smoothness across workstations.

OM

1

FORECASTING

Scientific proper approach estimation (different than prediction) (No tuka marna)

Estimating of future

Forecasting is the process of estimating or predicting future events, trends, or outcomes based on historical data, current information and analysis techniques.

Forecasting is the systematic process of predicting future values of a variable using past & present data with the help of stastical or mathematical models.

Commonly used in business, economic, weather prediction and supply chain management to support decision making.

Forecasting also helps in

- → production rate & production Budget
- → Plant expansion reqr or not.
- → Labour Budget
- → Product design & development reqr or not.

OM

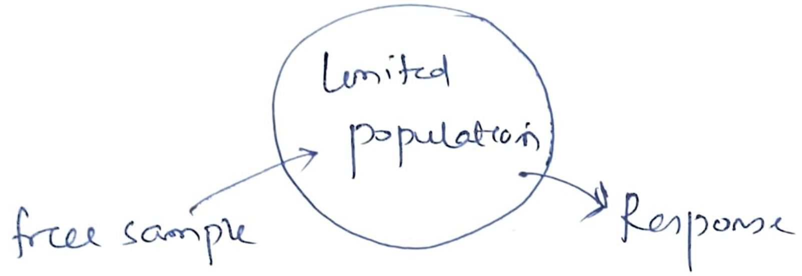
TYPES OF FORECASTING

- Qualitative (Long term) (2-3 years & more) (Detailed) or Subjective
  - New product (No past data thr or reqr)
  - Judgemental
    - (i) Market trial
    - Imp (ii) Delphi technique
    - (iii) opinion survey
    - (iv) Market research
- Quantitative or objective (Past data reqr) (Short term 2-6 months)
  - Time series
    - (i) Past average
    - (ii) Moving past average
    - (iii) Weighted moving past average
    - (iv) Exponential Smoothening ✓ Imp
  - Econometric or Casual
    - (i) Correlation
    - (ii) Regression

Qualitative / Long term / Judgemental / Subjective ⇒

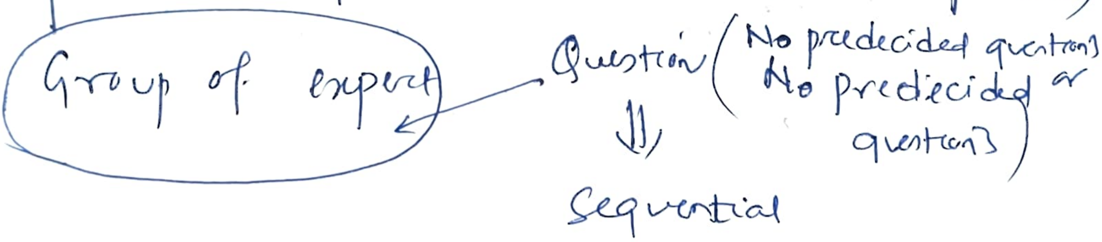
(i) Market trial ⇒

cutting in Newspaper



Costly method as product is distributed freely.

Best
(ii) Delphi technique ⇒ (Applicable for New product)



ex: Cricket experts in different fields

(iii) Market / Opinion ~~S~~urvey ⇒

Why - What - Cost

Asked to
customers, retailers, distributors to collect the data.

(iv)

What is happening in market

What customer wants.

Why it is required.

OM

(iv) Market research ⇒
Consultancy or External agency

Q23 Which of the following forecasting techniques is most suitable for making long range forecasts?

long range means qualitative / Subjective / ex: 3 years

(A) Time series analysis.

(B) Regression analysis.

(C) Exponential analysis

✓ (D) Market surveys

Quantitative / Objective / Short-term

(Old product) (Not applicable for new product as no past data is available)

→ Mathematical approach

→ past data reqr.

Time Series

(A) Past average

(B) Moving past average

(C) Weighted moving past average

(D) Exponential smoothing.

OM OM

Past Average

Demand / Month end

Forecast ↓ Month start

example given

Period	Demand	Forecast ?!
March	110	
April	120	
May	130	
June	120	$\frac{110+120+130}{3} = 120$
July	100	
August	140	

→ find out the forecast data for June using past average

Sept

$$\frac{110+120+130+120+100+140}{6}$$

↳ find out the forecast for september

If in question it is asked to find out forecast for upcoming month considering Last 4 months data then ?

for Sept → $n = 4$

$$\frac{130+120+100+140}{4}$$

OM

Moving past average

Fixed no. of period will be given.

Period	Demand	Forecast
March	110	
April	120	
may	130	
June	120	for June $(110+120+130)/3$
July	100	$(120+130+120)/3$ for July
August	140	$(130+120+100)/3$ for august
September		for september $\dfrac{120+100+140}{3}$

Keep $n=3$, find out moving average
↳ no. of period.

If it is asked to find out for october then ? As three consecutive demand data is not available, then the September month forecast is the forecast for October month also.

Weighted moving average

Past data is assigned with weightage.

Periods	Demand	Forecast ?!,
Jan	10	
Feb	20	
March	10	
April	30	
May	15	
June	25	

If No. of period = n

~~Weight sum of digit method~~

Weight by sum of digit method

Then $\sum n = \frac{n(n+1)}{2}$

$$\text{weight} = \frac{n}{\sum n}, \frac{n-1}{\sum n}, \ldots\ldots \frac{1}{\sum n}$$

Let $n = 4$

$$\sum n = \frac{4(4+1)}{2} = 10$$

then

$$\text{weight} = \frac{4}{10}, \frac{4-1}{10}, \frac{4-2}{10}, \frac{4-3}{10}$$

$$= 0.4, 0.3, 0.2, .01$$

OM

Σ weight must be one.

Question may?

june?

july? by weighted moving average.

given $n = 4$

Period	Demand
jan	$10 \times 0.1 = 1$
Feb	$20 \times 0.2 = 4$
march	$10 \times 0.3 = 3$
April	$30 \times 0.4 = 12$ /20
may	15
june	

To find out may forecast ?

Ans = 20

Recent is given to the maxm weightage

Forecast for may month

$= 30 \times 0.4 + 10 \times 0.3 + 20 \times 0.2 + 10 \times 0.1$

$= 12 + 3 + 4 + 1$

$= 20$

=

OM

Then for June forecast = 15 × 0.4 + 30 × 0.3 + 10 × 0.2 + 20 × 0.1

= 6 + 9 + 2 + 2 = 19

Period ~~Demand~~	Demand	Forecast for June !!
Jan	10	
Feb	20 × 0.1 =	2
march	10 × 0.2 =	2
april	30 × 0.3 =	9
may	15 × 0.4 =	6
June	25 . .	/19 (Ans)

Then for July

25 × 0.4 + 15 × 0.3 * 30 × 0.2 + 10 × 0.1

= 10 + 4.5 + 6 + 1

= 14.5 + 7 = 21.5 Ans

Smoothing

Q-19
Gate 2019

The table presents the demand of a product. By simple three-months moving average method, the demand forecast of the product for the month of september is :

Month	Demand
january	450
February	440
March	460
April	510
May	520
june	495
july	475
August	560

(A) 536.67
(B) 530
(C) 490
(D) 510

n = 3, moving average method

Forecast for september

$$\frac{495+475+560}{3} = 510$$

(Ans) option (D)

OM

If in questeon it is asked to find out the same by weighted movig average method then :

$$n = 3$$

~~weightes~~ $$\frac{n(n+1)}{2} = \sum n$$

weight = $\frac{n}{\sum n}, \frac{n-1}{\sum n}, \frac{n-2}{\sum n} \dots \frac{1}{\sum n}$

$$\sum n = \frac{3(3+1)}{2} = \frac{3\times 4}{2} = \frac{12}{2} = 6$$

weight = $\frac{3}{6}, \frac{3-1}{6}, \frac{3-2}{6},$

$= \frac{3}{6}, 2/6, 1/6$

$= 0.50, 0.33, 0.16$

Last three month to find out the forecast for September

June $495 \times 0.16 = 79.2$

July $475 \times 0.33 = 156.75$

August $560 \times 0.5 = 280$

September forecast = 515.95 Ans)

OM

Exponential Smoothing

Most used method.

It's a method under time series

⇓

coming under quantitative.

3 methods already we used.

- → Past avg
- → moving past avg
- → weighted moving avg

Lengthy calculation

past data reqr

For short term reqr, the use of past data with huge calculation is not so worthy

Most important reqrment ⇒

$$\left[\begin{array}{l}\text{Last month demand}\\ \text{Last month forecast}\end{array}\right]$$

So better than the 3 previous method.

⇑ Exponential smoothing method

ON

F_t = Forecast for period t.

F_t = forecast of t−1 period + α (Actual demand of (t−1) period − forecast of (t−1) period)

$$F_t = F_{t-1} + \alpha \left(D_{t-1} - F_{t-1} \right)$$

$$\boxed{F_t = F_{t-1} + \alpha \left(D_{t-1} - F_{t-1} \right)}$$

α = Smoothing Constant

$$\boxed{\alpha = \frac{2}{n+1}}$$

n = No. of periods

Weights is given exponentially decreasing order.

Weights = $\alpha, \alpha(1-\alpha), \alpha(1-\alpha)^2 \ldots\ldots$

OM

$$F_t = \alpha D_{t-1} + \alpha(1-\alpha) D_{t-2} + \alpha(1-\alpha)^2 D_{t-3} + \ldots\ldots$$

~~$F_t = \alpha D_{t-1} + (1-\alpha)[\alpha D_{t-2} +$~~

$$\Rightarrow F_t = \alpha D_{t-1} + (1-\alpha) \underbrace{\left[\alpha D_{t-2} + \alpha(1-\alpha) D_{t-3} + \ldots\ldots\right]}_{\Downarrow \; F_{t-1}}$$

$$\Rightarrow F_t = \alpha D_{t-1} + (1-\alpha) F_{t-1}$$

$$\Rightarrow \boxed{F_t = F_{t-1} + \alpha(D_{t-1} - F_{t-1})}$$

$$\boxed{(e)_{t-1} = D_{t-1} - f_{t-1} = \text{Error}}$$

$$\boxed{F_t = F_{t-1} + \alpha(e_{t-1})}$$

ON

Q-18 The sales of a product during the last four years were 860, 880, 870 and 890 units. The forecast for the fourth year was 876 units. If the forecast for the fifth year, using simple exponential smoothing, is equal to the forecast using a three period moving average the value of the exponential smoothing constant α is —

(A) 1/7 (B) 1.5 (C) 2/7 (D) 2/5

Given	Sales Demand		Forecast
1.	860		
2.	880		
3.	870		
4	890	—	876

Forecast for the 5th year using simple exponential
Using three period
smoothing = Forecast of three month moving average.

Forecast for 5th year

$$= \frac{880 + 870 + 890}{3} = 880 \quad \text{—(ii)}$$

OM

Forecast ~~using~~ by exponential smoothing

$$F_5 = F_4 + \alpha (D_4 - F_4)$$

$$\Rightarrow F_5 = 876 + \alpha (890 - 876) \rightarrow (i)$$

According to given :

givenes

$$880 = 876 + \alpha (890 - 876)$$

$$\Rightarrow 880 - 876 = \alpha (890 - 876)$$

$$\Rightarrow \alpha = \frac{4}{14}$$

$\Rightarrow \alpha = 2/7$ option (C) (Ans)

Q - 21 The sales of cycles in a shop in four consecutive months are given as 70, 68, 82 and 95. Exponentially smoothing average method with a smoothing factor of 0.4 is used in forecasting. The expected number of sales in the next month is

(A) 59

(B) 72

(C) 86

(D) 136

ay

	Sales / Demand	Forecasting
1	70	70
2	68	70
3	82	69.2
4	95	74.32
5		82.59 ≃ 86

$\alpha = 0.4$

$$F_t = F_{t-1} + \alpha (D_{t-1} - F_{t-1})$$

New method is applied

$\boxed{\text{Naive method}}$ Imp

According to Naive method, if forecast is not given then the Demand for the 1st one is taken as the forecast for that year/month. Then we have to find out the corresponding years/months ay

2nd $F_2 = F_1 + \alpha (D_1 - F_1)$

$\Rightarrow F_2 = 70 + 0.4 (70 - 70)$

$\Rightarrow F_2 = 70$

$F_3 =$

$= 70 + 0.4 (68 - 70)$

$= 69.2$

$F_4 =$

$=$ ~~70+~~ $69.2 + 0.4 (82 - 69.2)$

$F_4 = 74.32$

$F_5 = F_4 + \alpha ($

$= 74.32 + 0.4 (95 - 74.32)$

$= 82.59$

$\simeq 86$ (Ans) option c

OM

Properties

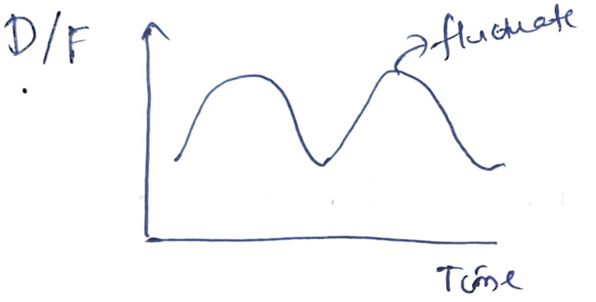
$$F_t = F_{t-1} + \alpha (D_{t-1} - F_{t-1})$$

$$\alpha = \frac{2}{n+1}$$

n = No. of periods

Smoothing constant

Responsiveness



D/F → Demand/forecast

Here α is high.

n → Less

We take less no. of period, So

α is high

for New product

If α = 1, as maxm

n = 1 less (i.e)

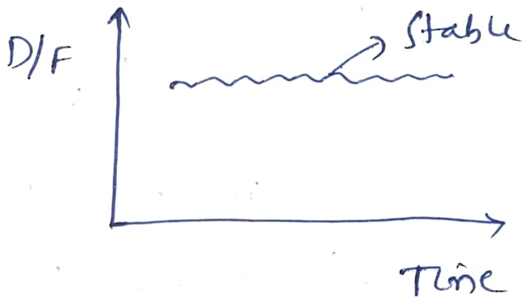
α → 0 to 1

then

$\boxed{F_t = D_{t-1}}$ this is called

Limit of Responsiveness

Stability



α → Low

n → higher

Used for Old existing product.

If α → 0 , n → 0

then $\boxed{F_t = F_{t-1}}$ called

Limit of Stability

OM

Imp

If $\alpha \uparrow$ we are moving towards Responsiveness

If $n \uparrow$ moving towards Responsiveness.

Error

e or $\Delta = D_t - F_t$

mismatch between demand & forecast.

(i) Mean absolute deviation ⇒ (MAD)

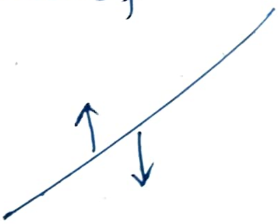
$$\boxed{MAD = \sum_{t=1}^{n} \frac{|D_t - F_t|}{n}}$$

Only gives magnitude of error as mod is thr.

only we can know the quantity.

It doesn't tell about direcn of error

i.e +ve or -ve. we are unable to ~~fi~~ know.



(ii) Mean Forecast Error ⇒ (MFE or BIAS)

$$BIAS = \sum_{t=1}^{n} \frac{(D_t - F_t)}{n}$$

Consider sign: +ve and -ve.

If BIAS +ve ⇒ i.e. Demand is more compared to forecast.

it is called Under forecast

If BIAS -ve ⇒ Demand is less & we are forecasting more

it is called over forecast.

It tells the direction of error.

ent one

(iii) Mean Square Error (MSE)

$$MSE = \sum_{t=1}^{n} (D_t - F_t)^2 / n$$

$$= \frac{\Sigma (e_t)^2}{n}$$

[illegible]

$\sqrt{SME}$ = standard deviation (σ)

we put square root then ⟶

But ⟹

MSE, MAD, BIAS (or MFE)

Q- In a time series forecasting model, the demand for five time periods was 10, 13, 15, 18 and 22. A linear regression fit resulted in a equation :

F = 6.9 + 2.9t where F is the forecast for period t. The sum of absolute deviations for the five data is

(A) 2.2 (B) 0.2 (C) −1.2

(D) 24.3

Absolute deviation means
= 22.

	Demand	Forecast	Σ Error $(D_i - F_i)$
1	10	$6.9 + 2.9 \times 1 = 9.8$	$\lvert 10 - 9.8 \rvert = 0.2$
2	13	$6.9 + 2.9 \times 2 = 12.7$	$\lvert 13 - 12.7 \rvert = 0.3$
3	15	$6.9 + 2.9 \times 3 = 15.6$	$\lvert 15 - 15.6 \rvert = 0.6$
4	18	$6.9 + 2.9 \times 4 = 18.5$	$18 - 18.5 = 0.5$
5	22	$6.9 + 2.9 \times 5 = 21.4$	$= 0.6$

$\Sigma = 2.2$

given $F = 6.9 + 2.9t$

Absolute deviation = 2.2

if $MAD = \frac{2.2}{4}$
asked then

$\boxed{\text{Absolute deviation} = 2.2}$ (Ans)

Q-24 A dealer for washing m/c forecasts the demand at the rate of 600 units per month for the next four months. The actual demand is found to be 500, 650, 800 and 900 units. The (MAD) and BIAS are found to be ________ and ________.

OM

F = 600 for next four months

Actual demand	given Forecast	$D_i - F_i$
500	600	−100
650	600	50
800	600	200
900	600	300

for MAD $\frac{\sum |D_i - F_i|}{n}$

for BIAS $\frac{\sum (D_i - F_i)}{n}$

$$MAD = \frac{\sum |D_i - F_i|}{n}$$

$$= \frac{100 + 50 + 200 + 300}{4} = 162.5$$

$$BIAS = \frac{-100 + 50 + 200 + 300}{4} = 112.5$$

OM

Q-22

"In exponential smoothening method, which one of the following is true?

(A) $0 \leq \alpha \leq 1$ and high value of α is used for stable demand.

[✓ (B)] $0 \leq \alpha \leq 1$ and high value of α is used for unstable demand.

(C) $\alpha \geq 1$ and high value of α is used for stable demand.

(D) $\alpha \leq 0$ and high value of α is used for unstable demand.

$0 \leq \alpha \leq 1$

α is high for unstable demand

option (B) is correct answer.

INVENTORY

Inventory functions, types and classification. Inventory models: EOQ (Economic Order Quantity), reorder point, safety stock. Inventory management techniques: ABC, VED, FSN, JIT (Just-in-Time).

Inventory refers to the **stock of goods, materials, and supplies** that an organization holds for production, resale, or day-to-day operations.

It acts as a buffer between supply and demand.

Inventory is essential to provide flexibility in operating a system.

Inventory management is the process of **planning, controlling, and monitoring inventory levels** so that the right materials are available at the right time, in the right quantity, and at minimum cost.

Importance of Inventory

- Ensures **smooth production flow**.
- Meets **customer demand on time**.
- Helps manage **uncertainty in supply & demand**.
- Supports **bulk purchasing advantages**.

Main objectives of inventory management are:

- Ensure **continuous supply** of materials and finished goods.

- **Minimize investment** in inventory (avoid excess stock).

- Reduce **wastage, pilferage, and obsolescence.**

- Balance **between carrying cost and ordering cost.**

- Improve **customer service** by avoiding stock-outs.

Classification of inventory/ Types of Inventory

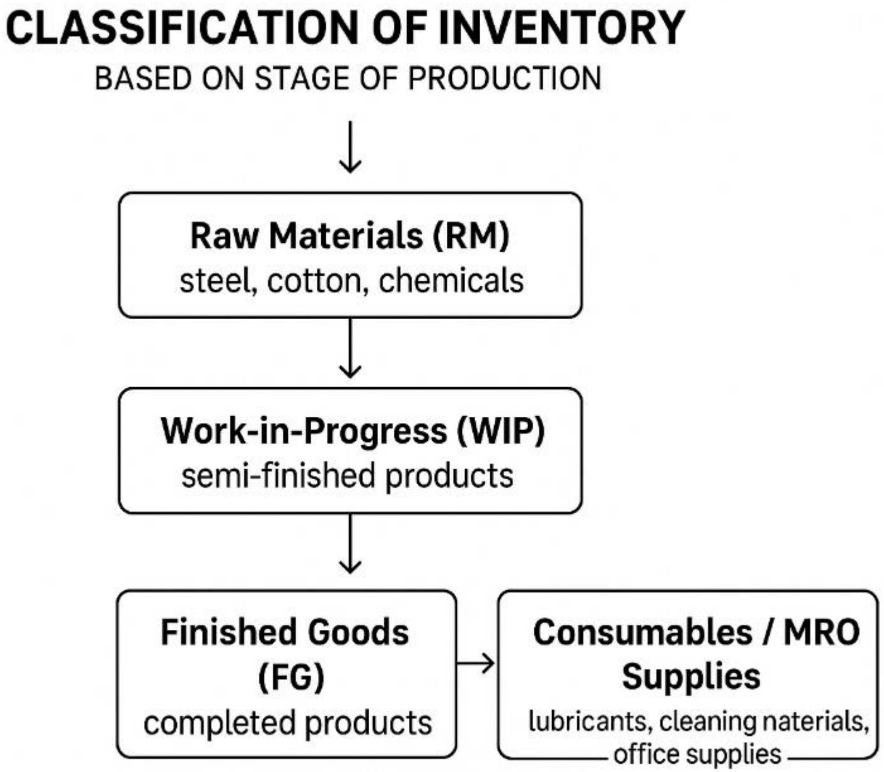
(A) Based on Stage of Production:

Raw Materials inventory: Basic inputs used for production (steel, cotton, chemicals). Remove dependency between suppliers and plants.

Work-in-Progress inventory: Semi-finished products still in process. Remove dependency between machines of a product line.

Finished Goods inventory: Completed products ready for sale. Remove dependency between plant and its customers/market.

Miscellaneous inventory (Consumables / MRO Supplies): Items needed for operations but not part of the final product (lubricants, cleaning materials, office supplies).



(B) Based on Function

- **Cycle Stock:**

  Regular stock held to meet normal demand.

- **Safety Stock:**

  Extra stock to cover uncertainties in demand/supply.

- **Pipeline (Transit) Stock:**

  Stock moving through supply chain (in transit from supplier to buyer).

- **Anticipation Stock:**

  Built up in advance to meet seasonal demand or price hikes.

- **Decoupling Stock:**

  Buffers between different stages of production to avoid stoppages.

TYPES OF INVENTORY

A. Based on Stage of Production

- **Raw Materials (RM):** Inputs used in production (steel, cotton)
- **Work-in-Progress (WIP):** Semi-finished goods (car chassis, dough)
- **Finished Goods (FG):** Completed products ready for sale
- **MRO Supplies:** Maintenance, repair, operating items (lubricants, tools)
- **Packing Materials:** Cartons, bubble wrap, etc.

B. Based on Function

- **Cycle Stock:** Regular stock to meet normal demand.
  Example: Weekly stock of groceries in a store
- **Safety Stock:** Extra stock for uncertainties in supply/demard.
  Example: Extra medicines in a pharmacy during flu season
- **Pipeline (Transit) Stock:** Inventory in transit or between stages
  Example: Goods being shipped from supplier to warehouse
- **Decoupling Stock:** Buffers betwıen different processes to avoid delays

Classification of Inventory

(i) By Usage Value (ABC Analysis)

- **A-items:** High-value, low-quantity → strict control.
- **B-items:** Moderate value & control.
- **C-items:** Low-value, high-quantity → simple control.

(ii) **By Criticality (VED Analysis)**

- **Vital:** Must-have items.
- **Essential:** Needed but not as critical.
- **Desirable:** Can be substituted/optional.

(iii) **By Movement (FSN Analysis)**

- **Fast-moving** → sold/used frequently.

- **Slow-moving** → used less often.
- **Non-moving** → obsolete/rarely used

(iv) **By Demand**

- **Independent Demand:** Customer-driven (finished goods).
- **Dependent Demand:** Based on other items (raw materials, parts)

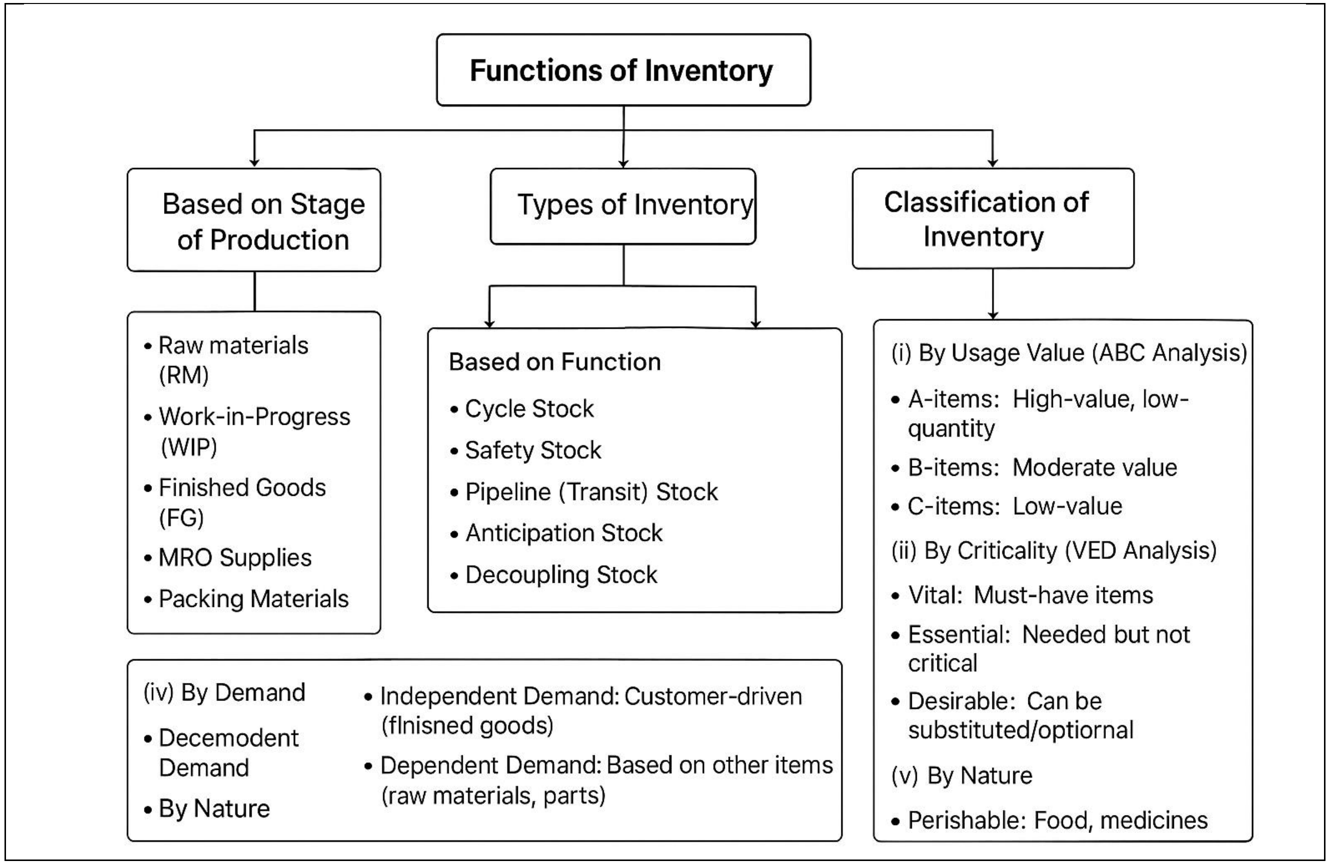
(v) **By Nature**

- **Perishable:** Food, medicines.
- **Non-perishable:** Machinery, spare parts.

So, in short:

- **Stage** → RM, WIP, FG, MRO
- **Function** → Safety, Cycle, Pipeline, Anticipation, Decoupling

- **Usage Value** → ABC
- **Nature** → Perishable / Non-perishable
- **Demand** → Independent / Dependent


Functions of Inventory
Based on Stage of Production
Types of Inventory
Classification of Inventory
• Raw materials (RM)
• Work-in-Progress (WIP)
• Finished Goods (FG)
• MRO Supplies
• Packing Materials
Based on Function
• Cycle Stock
• Safety Stock
• Pipeline (Transit) Stock
• Anticipation Stock
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(iv) By Demand
• Decemodent Demand
• By Nature
• Independent Demand: Customer-driven (flnisned goods)
• Dependent Demand: Based on other items (raw materials, parts)

Inventory Decisions:

The following two basic inventory decisions are generally taken by managers.

When to replenish the inventory of that item.

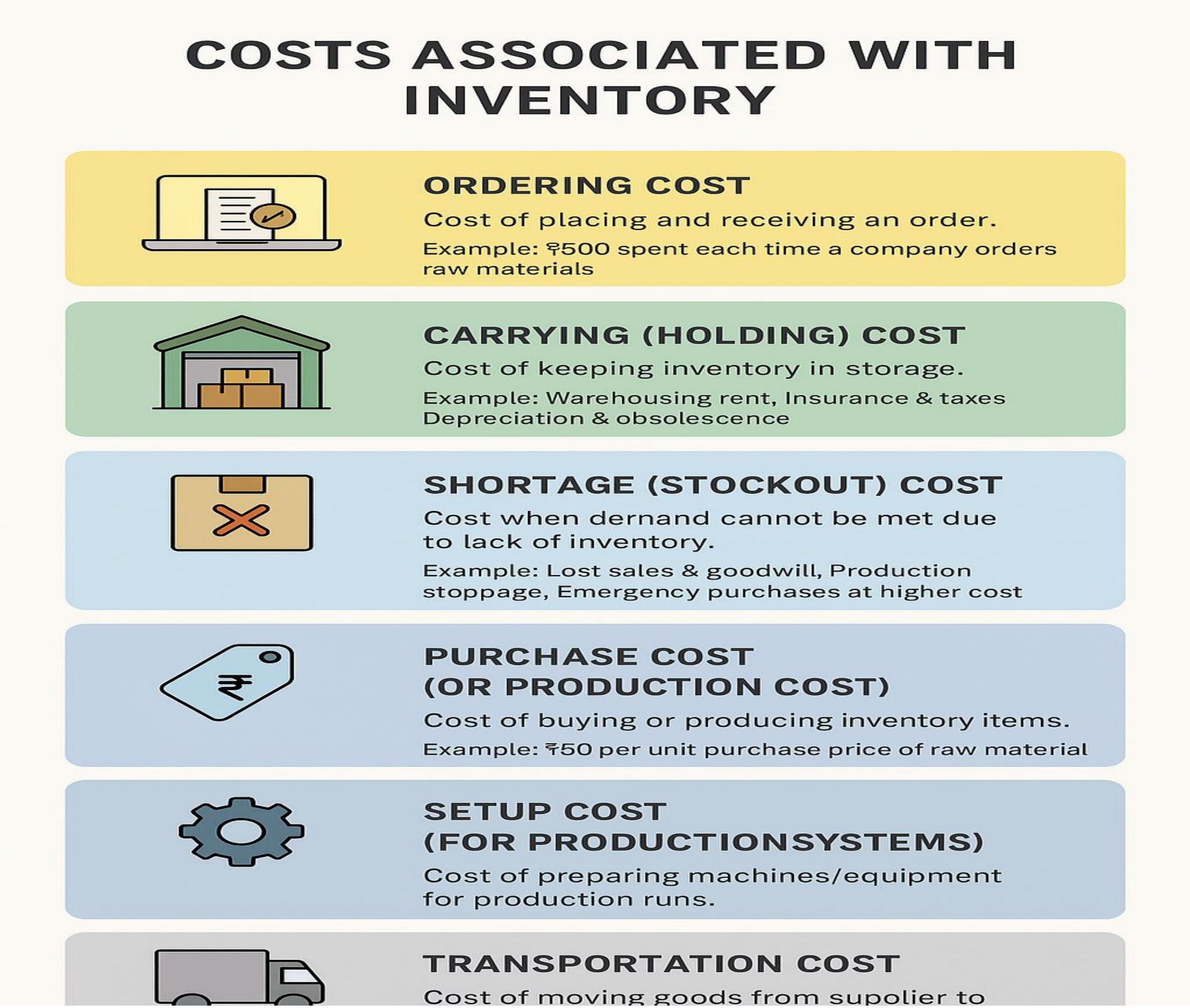
How much of an item to order when the inventory of that item is to be replenished?

COST ASSOCIATED WITH INVENTORY

Inventory Costs			
Purchase cost (C) Or Nominal cost or material cost or Unit cost of item	Ordering Cost (C_o) Or Set up Cost	Holding Cost (C_h) or Carrying Cost (C_c) Cost associated with storing an item in the inventory. Expressed	Back-order Cost (C_b) Or Shortage Cost (C_s)

(Cost incurred in buying from outside sources. Cost may vary according to the quantity purchased.) Ex- Unit price Rs 20 for upto 100 units, Rs 19.50 for more than 1000 units)	Or Procurement Cost Independent to the order size. Set up cost means when internally produced. Procurement cost means if ordered or	in terms of rate per unit. Rent	Cost incurred when customers are not being served. Shortages. Loss of profit Loss of reputation Rescheduling cost

	procured from outside. During outsourcing employees cost, documentation cost, inspection cost, Transportation cost , reject-delay cost included.		



COSTS ASSOCIATED WITH INVENTORY

ORDERING COST

Cost of placing and receiving an order.

Example: ₹500 spent each time a company orders raw materials

CARRYING (HOLDING) COST

Cost of keeping inventory in storage.

Example: Warehousing rent, Insurance & taxes
Depreciation & obsolescence

SHORTAGE (STOCKOUT) COST

Cost when demand cannot be met due to lack of inventory.

Example: Lost sales & goodwill, Production stoppage, Emergency purchases at higher cost

PURCHASE COST (OR PRODUCTION COST)

Cost of buying or producing inventory items.

Example: ₹50 per unit purchase price of raw material

SETUP COST (FOR PRODUCTIONSYSTEMS)

Cost of preparing machines/equipment for production runs.

TRANSPORTATION COST

Cost of moving goods from supplier to

If the order quantity is less, the cost of order will be more, but the inventory carrying cost will be less.

On the other hand, if the order quantity is more, the ordering cost will be less, but the carrying cost will be more. These are shown in figure below.

In figure, the total cost curve represents the sum of ordering cost and carrying cost for each order size. The order size at which the total cost is minimum is called Economic Order Quantity (EOQ) or Q* (optimal order size).

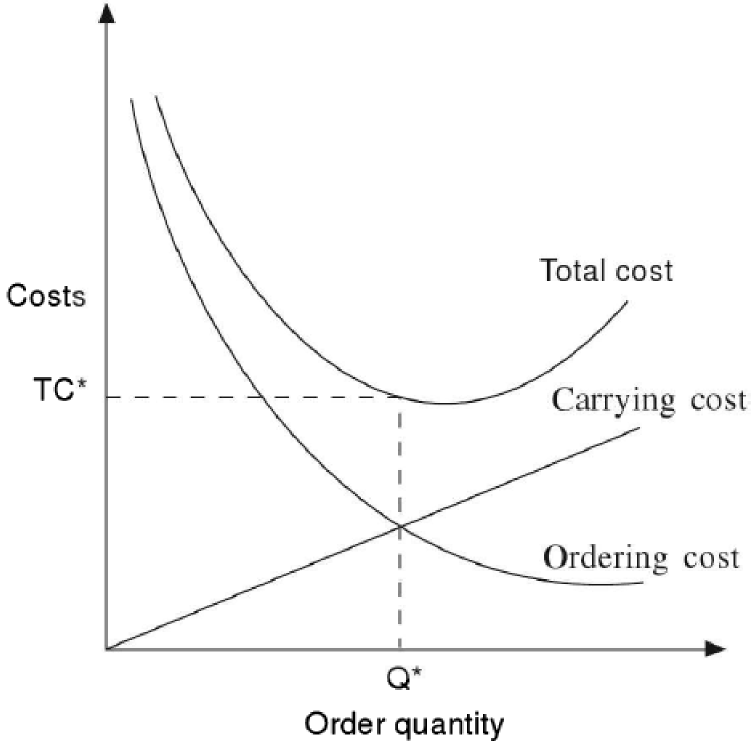


Fig. 9.1 Trade-off between costs.

INVENTORY MODELS

Inventory models are mathematical approaches used to **determine optimal order quantity (i.e. how much quantity is required), reorder point i.e. lead time, and safety stock** for minimizing total inventory cost and meet customer demand effectively.

Deterministic Models (Ideal Case) When demand is known and constant	Probabilistic Models (Real World Situation) When demand is unknown/uncertain/random	Special Inventory Models
1. Economic Order Quantity (EOQ model) 2. EOQ with Price Break	1. Fixed Order Quantity System (Q-System) 2. Fixed Period System (P-System)	1. Single Period Model (Newsvendor Problem): Used for Perishable/seasonal

3. Production or Build-up model 4. Shortage Model	3. Safety Stock Model 4. Service Level Model	goods (ex-Newspapers, Fashion items). Balances cost of understocking vs overstocking 2. ABC/FSN/VED based Models: Analytical models used for controlling specific categories of items.

Inventory

Physical stock in hand.

70% of cost is spent in inventory

Plant will smoothly run

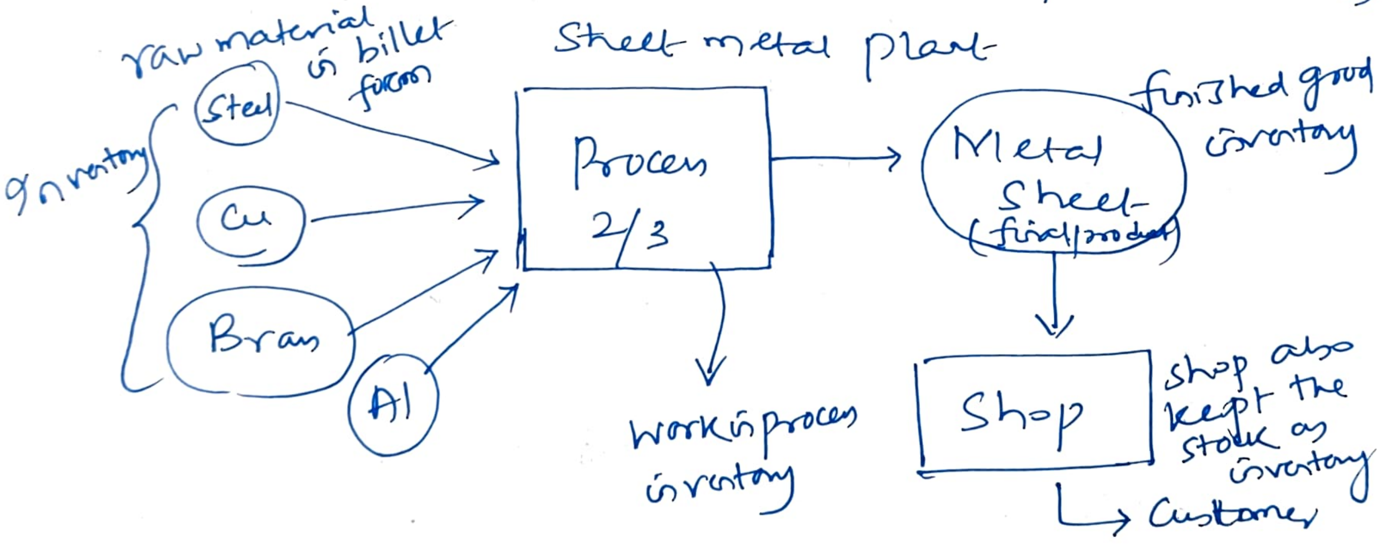
Efficient running of plant if inventory is maintained.

Aim of Inventory

>> Minimise the investment in inventory.

>> Maximize service level to the customer.
(to fulfill the demand of a customer)

Sheet metal plant



Raw material inventory

Work in process inventory

Finished good inventory

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∴ Example of Inventory

- » Raw material inventory
- » Work in process inventory (for Semi-finished product)
- » Finish good inventory
- » Misc. inventory (ex: Cotton, cutting fluid, lubricating oil etc.)

Cost associated with inventory

- (C) Purchase cost or (material cost) or (Unit cost of item)
- (C_o) Ordering cost or (Set up cost) or (Procurement cost)
- (C_h) Holding or (C_c) cost or (Carrying cost)
- (C_b) Back order or (C_s) cost or (Shortage cost)

C = unit cost of item (Cost/unit)

⇒ Ordering cost
⇒ for out source

Set up cost
⇒ for internally produce

Hence in ordering cost includes

during Outsourcing → employee cost
→ documentation cost
→ Inspection cost

OM

→ Transportation Cost

→ Reject - delay cost

For Set up cost $\xrightarrow{\text{When}}$ Internally produce
means

⇒ Holding Cost

Rent

Insurance Cost

Locked up capital interest

Employee used

Damaged - Depriciation cost

⇒ Back order Cost
or Shortage Cost

- Loss of profit
- Loss of reputation
- Rescheduling cost

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C = Cost / unit

C_o = Ordering cost / order

C_h = Holding cost / unit / year

C_b or C_s = Shortage cost / unit

Inventory Models

- How much quantity
- Lead time
  Reorder level

(Ideal case)
Deterministic Models
(when demand is known)

- imp ⇒ Economic order quantity (EOQ model)
- ⇒ EOQ with price break
- ⇒ Production or Buildup model
- ⇒ Shortage model

(Real world situation)
Probablistic Models
(when demand is unknown)

- Demand & profit model
  or
  static inventory model

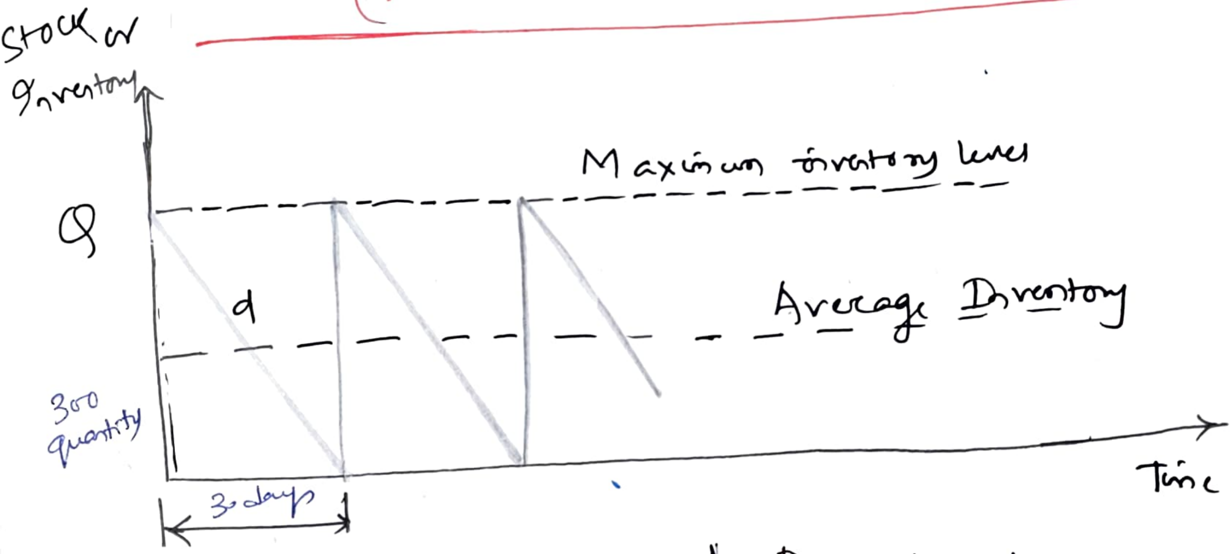
Deterministic Model

Demand or consumption is constant

Infinite rate of ~~replenishment~~ replenishment.
(Instantaneous)

Lead time constant.

Model-1 (I) Economic Order Quantity or (Wilsson and Harris Model)



T = cycle time

d = Demand rate

Example 300 cars need to be sell in one month.

demand rate d = 300 consumed in 30 days

ie $\frac{300}{30} = 10$ cars per day

Once consumption is zero, once again inventory level raise to Q as infinite rate of replenishment is there. So instantaneously inventory level increase once consumption reaches to zero, like that cycle continues.

ON

If in each month we ordered 300 quantity demand, then

annual demand = 300 × 12

∴ No. of orders = 12

* In EOQ model No safety stock

No shortage

As ideal condn is thr.

Annual demand = D

⇒ Holding Cost ⇒

From Average inventory we can able to find Holding cost per year.

Holding cost ⇐

$$\text{Average Inventory} = \frac{\text{Average of } \Delta}{\text{Base}}$$

$$= \frac{\frac{1}{2} \times Q \times T}{T}$$

$$= Q/2$$

Holding cost / year = Average Inventory × Holding cost

OM

No shortage
No safety stock(✗) reqd.

In this model of inventory, orders of equal size are placed at periodical intervals.

The items against an order are replenished instantaneously and the items are consumed at a constant rate.

The purchase price or purchase cost per unit is same irrespective of order size.

Let D = Annual demand in units.

C = purchase price or purchase cost per year

d = Demand rate

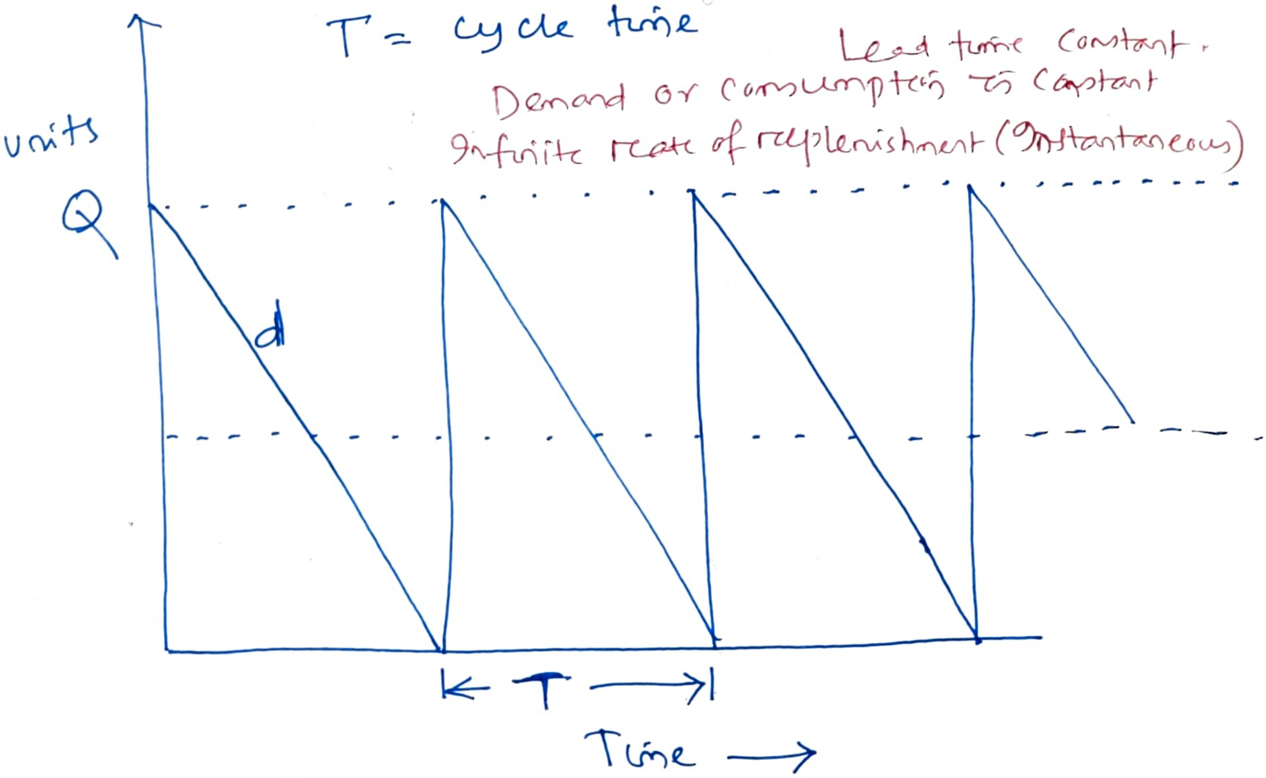
Q = Quantity or order size

C_0 = ordering cost / order

C_c or ~~C_a~~ C_h = Carrying cost or holding cost / unit / year

T = cycle time

Lead time constant.
Demand or consumption is constant
Infinite rate of replenishment (Instantaneous)



Purchase model without stockout

∴ Number of orders/year $= \frac{D}{Q}$

Average inventory $= Q/2$

(Average inventory

$= \frac{\text{Average of } \Delta}{\text{Base}}$

$= \frac{\frac{1}{2} Q T}{T} = Q/2$)

⇒ Cost of ordering/year

or Ordering cost/year =

(Number of orders/year) × ordering cost/ord

$= \frac{D}{Q} \times C_0$

⇒ Holding cost or carrying cost/year

= Average inventory × Holding cost

$= \frac{Q}{2} \times C_h$

⇒ ~~Annual Demand or~~ purchase cost/year

= Annual demand × Cost per unit or unit cost

$= D \times C$

∴ Total cost = Purchase cost + Ordering cost + Holding or carrying cost

$$\boxed{\therefore C = D \times C + \frac{D}{Q} \times C_o + \frac{Q}{2} C_h}$$

Everything is constant except Q.

So differentiating w.r.t Q.

$$\frac{d(T.C)}{dQ^*} = \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

$$\Rightarrow \quad = \frac{-D}{Q^2} C_o + \frac{1}{2} C_h$$

The second derivative $= \frac{+2D}{Q^3} C_o$

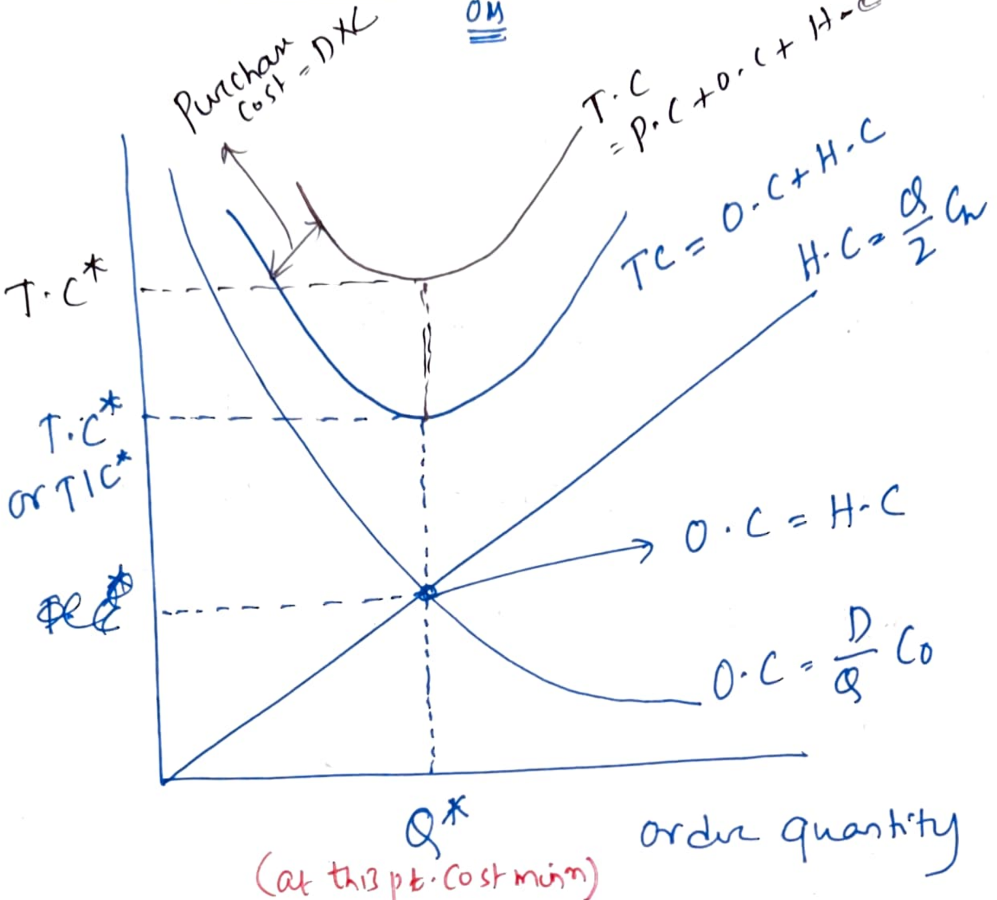
Since the second derivative is positive, we can equate the first derivative to zero to get the optimal value of Q.

$$\frac{-D}{Q^2} C_o + \frac{C_h}{2} = 0$$

$$\Rightarrow \quad Q^2 = \frac{2 C_o D}{C_h}$$

$$\Rightarrow \quad \boxed{Q^* = \sqrt{\frac{2 D C_o}{C_h}}}$$

OM



Trade-off between costs

Put $Q^* = \sqrt{\frac{2DC_0}{C_h}}$ to find $(T.C)_{at\, Q^*}$

$$T.C = \frac{D}{Q} C_0 + \frac{Q}{2} C_h$$

As at Q^* O.C = H.C

$\therefore$ T.C = 2 O.C or 2 H.C

$\Rightarrow$ T.C = 2 × H.C

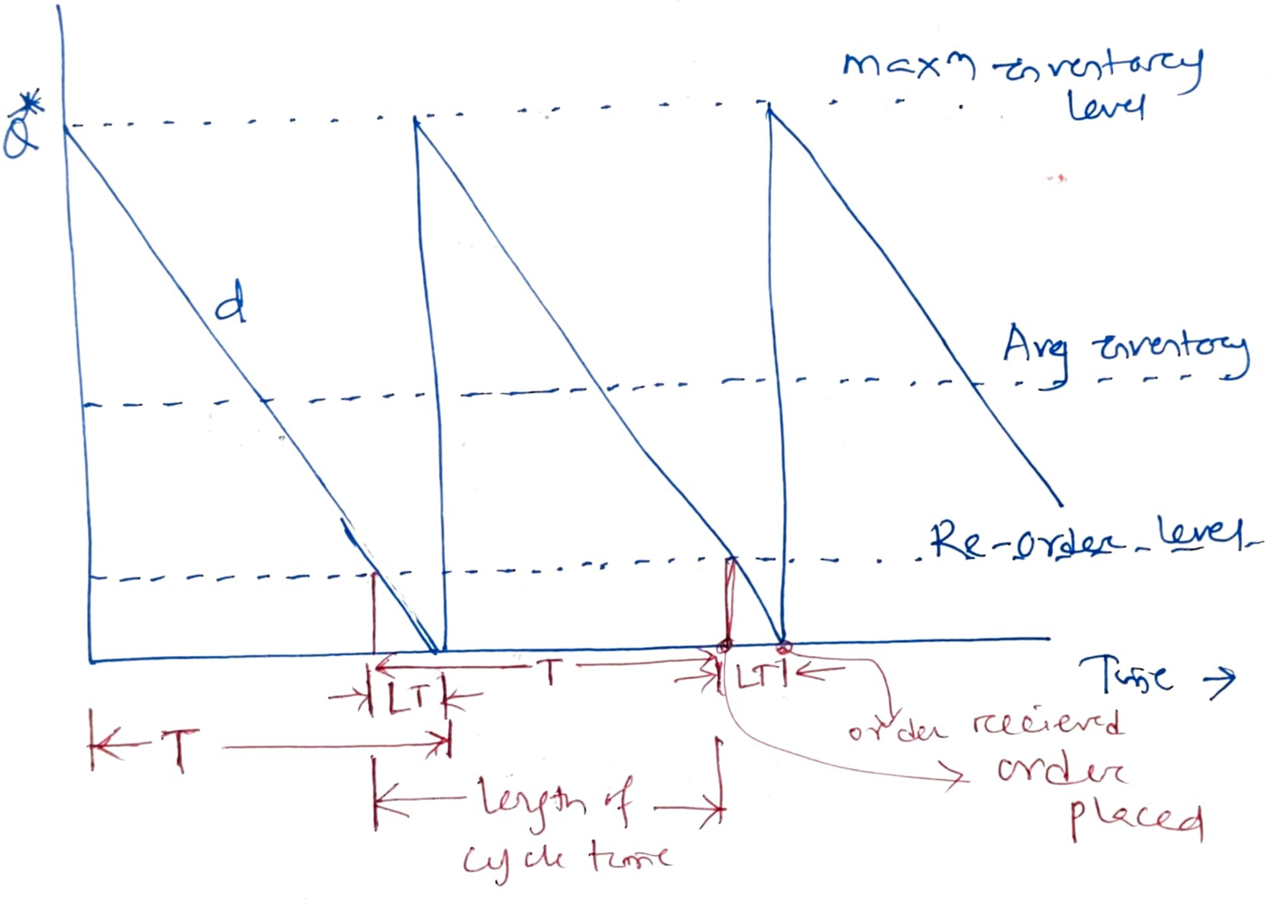
$$= 2 \times \frac{1}{2} \times Q\, C_h$$

$$= 2 \times \frac{1}{2} \times Q^* C_h$$

$$\Rightarrow T.C = 2 \times \frac{1}{2} \times \sqrt{\frac{2 D C_0}{C_h}} \times C_h$$

$$\boxed{\Rightarrow (T.C)_{\text{at } Q^*} = \sqrt{2 D C_0 C_h}}$$

or TIC → Total inventory cost



Lead Time (LT) ⇒ The time between placing an order with a supplier and receiving the goods.

ex:- If a company orders raw material on 1st sept and receives them on 10th sept; the lead time = 9 days

Formula

⇒ Optimum Number of order/year

$$\boxed{N^* = \frac{D}{Q^*}}$$

⇒ Length of cycle time = Time betn two Sucessive order

$$\boxed{\underset{\text{cycle time}}{T^*} = \frac{Q^*}{D}}$$

or we can also write :

$$\Rightarrow \quad T^* = \frac{1}{D/Q^*} = \frac{1}{N^*}$$

$$\Rightarrow \quad \boxed{T^* = \frac{1}{N^*}} \text{ in year}$$

$$\text{or} \quad \boxed{1 = T N^*}$$

$$\Rightarrow \quad \boxed{\text{Reorder level} = \text{L.T} \times \text{Demand rate}}$$

⇒ Sometimes holding cost is given in %ag

of purchase cost i.e

$$\boxed{C_h = i\,\%\text{ of } C_p \Rightarrow C_h = iC}$$

Total cost = Purchase cost + Ordering cost

+ Holding or Carrying Cost

= Annual demand × cost per unit

$(D \times C)$

+ (D/Q) × ordering cost/year

C_0

No. of order/year =

C = purchase price per year

D = Annual demand = 10,000

Q = Quantity = 1000

No. of order = $\frac{10,000}{1000} = 10$

+ (Average inventory) C_h

↳ $Q/2$

$$\Rightarrow \boxed{T.C = D \times C + \frac{D}{Q} C_0 + \frac{Q}{2} C_h}$$

Everything is constant except Q.

So, differentiating w.r.t Q.

$$\frac{d(T.C)}{dQ^*} = \frac{D}{Q} C_0 + \frac{Q}{2} C_h$$

$$= \frac{-D}{Q^2} \cdot C_0 + \frac{1}{2} C_h$$

⇒

The second derivative = $+\frac{2DC_0}{Q^3}$

OM

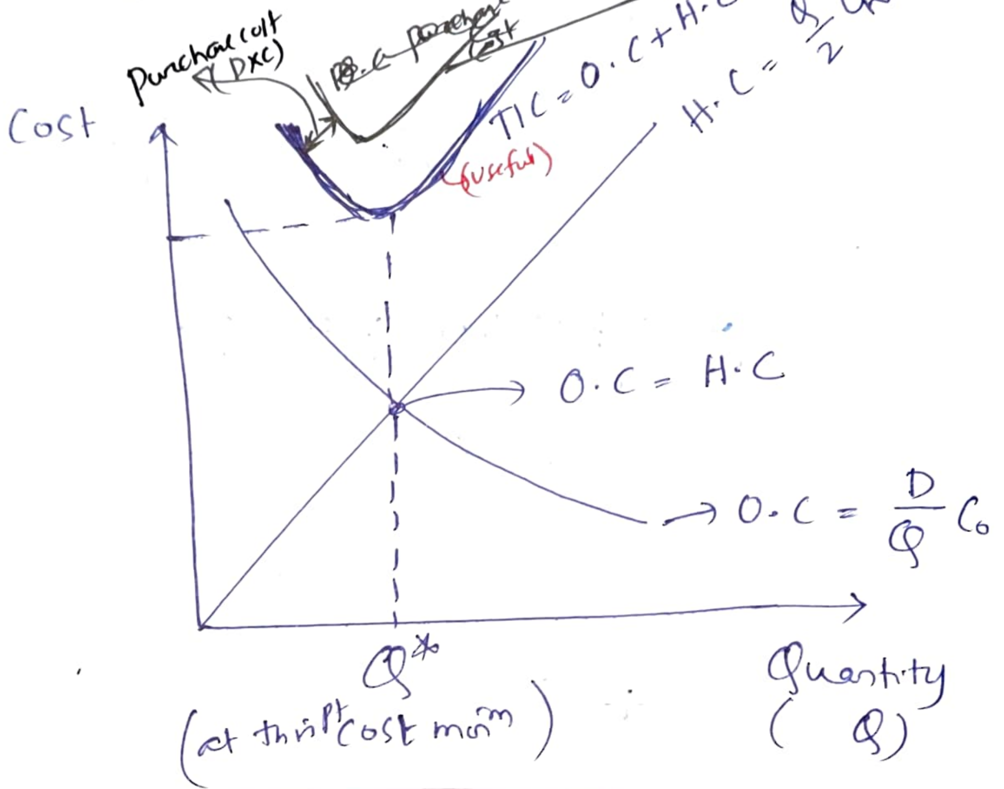
imp

$$\Rightarrow \boxed{Q^* = \sqrt{\frac{2DC_o}{C_h}}}$$

Since the second derivatu is +ve, we can equat the first derivative to zero to get the optimal value of Q.

Economic order quantity

Total cost = P.C + O.C + H.C



$$TIC = \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

total inventory cost

[In question of DXC if purcha is said to includ othe n

Ordering cost

As quantity ↑ cost ↓

D & C both constant.

but ⇒

- If Q ↑ No. of order will be reduce then ordering cost will be low.
- If quantity ↑ then average inventory ↑ then holding cost will be high

So we have to balance both the cost to find out the optimum quantity Q with min cost.

Imp

Put $Q^* = \sqrt{\frac{2DC_o}{C_h}}$ $\Rightarrow$ $\boxed{Q^* = \frac{2DC_o}{C_h}}$

TIC at Q^*

As at Q^* O.C = H.C -

So we can write

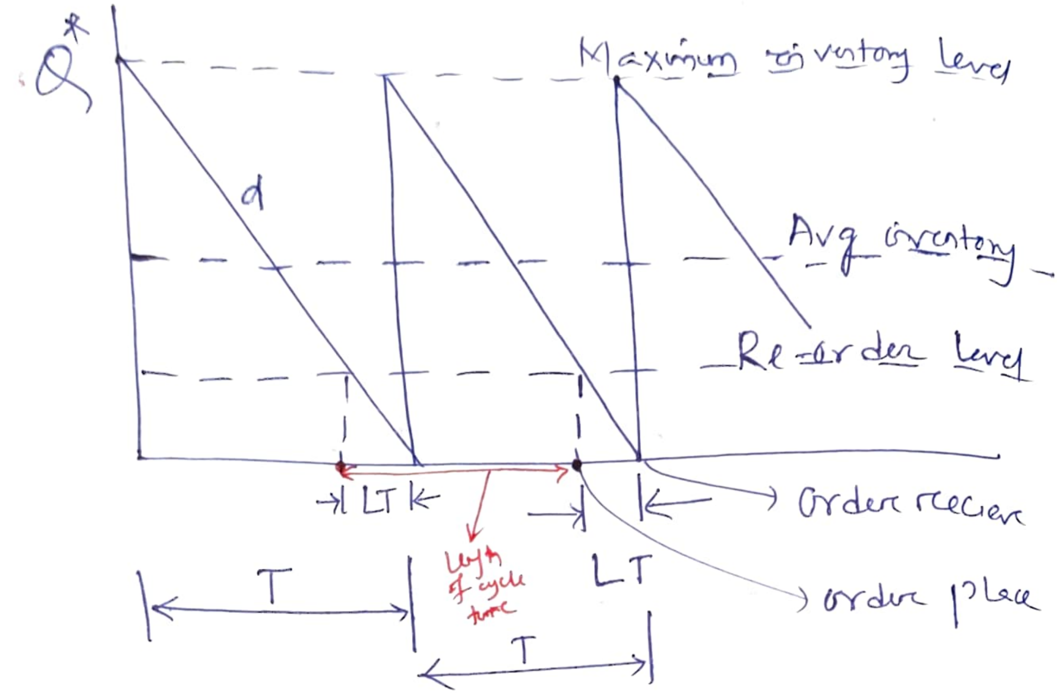
$$TIC = \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

or O.C + H.C

= 2 O.C or 2 H.C

$$\Rightarrow TIC = 2 \times \frac{1}{2} \times \sqrt{\frac{2DC_o}{C_h}} \, C_h$$

$$\boxed{(TIC)_{\text{at } Q^*} = \sqrt{2 D C_o C_h}}$$



LT = Lead time

⇒ Time betn placing the order with a supplier & receiving the order.

Formula

Optimum number of order/year

$$\frac{D}{Q^*} = N^*$$

Length of cycle time = time betn two successive order.

$$= \frac{Q^*}{D} = T^* \text{ cycle time}$$

$$\Rightarrow T^* = \frac{1}{N^*} \text{ in year}$$

$$\Rightarrow 1 = TN^*$$

$$\boxed{\text{Reorder level} = L \cdot T \times \text{demand rate}}$$

=

$$\boxed{\begin{aligned} C_h &= i\ \%\ \text{of}\ C \\ &= iC \end{aligned}}$$

Sometimes C_h is given in %.age of purchase cost.

Q-5 Market demand for springs is 8,00,000 per annum. A company purchases these spring in lots. and sell them. The cost of making a purchase order is Rs 1200. The cost of storage of springs is Rs 120 per stored piece per annum. The economic order quantity is

(a) 400 (b) 2828 (c) 4000 (d) 8000

$D = 8{,}00{,}000$

$C_0 = 1200$

$C_h = 120$

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

$$= \sqrt{\frac{2 \times 800000 \times 1200}{120}}$$

$$Q^* = 4000$$

Q-14 An item can be purchased for Rs 100. The ordering Cost is Rs 200 and the inventory carrying cost is 10% of the item cost per annum. If the annual demand is 4000 units, the economic order quantity (in units) is

(A) 50 (B) 100 (C) 200 (D) 400

$C = 100$ $D = 4000$ units

$C_o = 200$ $C_h = 10\%$ of 100
$= 10$ /unit/year

$$Q^* = \sqrt{\frac{2DC_o}{C_h}} = \sqrt{\frac{2 \times 4000 \times 200}{10}}$$

$$\Rightarrow Q^* = 400$$

Q-16 Consider the following data with reference to elementary deterministic economic order quantity model

Annual demand of an item	10000
Unit price of the item (in Rs)	10
Inventory Carry Cost per unit per year (Rs)	1.5
Unit order cost (in Rs)	30

The total nos of economic orders per year to meet the annual demand is ______

$N^* = ?$

Given $D = 10,0000$

$C = 10$

$C_h = 1.5$

$C_0 = 30$

$$Q^* = \sqrt{\frac{2D\,C_o}{C_h}} = \sqrt{\frac{2 \times 10^5 \times 30}{1.5}}$$

$$\Rightarrow Q^* = 2000$$

$$N^* = \frac{\text{Demand } (D)}{\text{optimum quantity } (Q^*)}$$

$$\Rightarrow N^* = \frac{D}{Q^*} = \frac{10^5}{2000}$$

$\Rightarrow N^* = 50$ orders per year.

If cycle time is asked then
(in days)

we know $T^* = \dfrac{1}{N^*}$

$$= \frac{365 \text{ days}}{50}$$

$=$ in days.

OM

Q.17 The annual demand of valves per year is a company is 10000. The current ord quantity is 400 per order. The holding cos of valve is Rs 24 per valve per year and the ordering cost is Rs 400 per order. If the current order quantity is changed to economic order quantity, then the saving is the total cost of inventory per year will b Rs _____________.

$D = 10000$ $Q = 400$ per ~~year~~ order

Case I $Q = 400$ $C_h = 24$

$C_o = 400$

TIC = Total inventory cost

$$= O.C + H.C$$

$$= \frac{D}{Q} \times C_o + \frac{Q}{2} C_h$$

$$= \frac{10,000}{400} \times 400 + \frac{400}{2} \times 24$$

$$= 14800$$

Case - II when $Q = EOQ$ ie Q^*

TIC at $Q^* = \sqrt{2 D C_o C_h}$

$= \sqrt{2 \times 10{,}000 \times 400 \times 24}$

$= 13856.4$

$\therefore$ Saving $= 14800 - 13856.4$

$= 943.6$ Rs. (Ans)

Q.

A manufacturer purchases item in lots of 1000 units, which is a requirement for one quarter. The cost per unit is Rs 200. The ordering cost is Rs 100 per order. The quarterly inventory carrying cost rate is 5%. Find out the following:

(a) EOQ

(b) Total Annual Cost

(c) Saving due to EOQ purchase

Solve it.

Quarterly inventory carrying cost = 5%

That means 5% per quarter

⇒ Annual carrying cost rate = 5% × 4

= 20%

Cost per unit = Rs 200/— = C

~~So annual~~ quarterly carrying cost = 5%

∴ Annual carrying cost or annual handling

cost = i% of C

= (5 × 4) % of C

= 0.2 × 200 = Rs 40 / unit-year

OM

Again Given 1000 units requirement for one quarter

$\therefore$ Annual Demand (D) $= 4 \times 1000$

$= 4000$

Ordering cost $= C_o =$ Rs 100 /order

(a) EOQ $= Q^* = \sqrt{\dfrac{2DC_o}{C_h}}$

$$= \sqrt{\frac{2 \times 4000 \times 100}{40}}$$

$$= \sqrt{20000}$$

$$\simeq 141.42$$

So, EOQ $= 141$

(b) Total annual cost at EOQ

Purchase Cost $= D \times C$

$= 4000 \times 200$

$= 800,000$

Ordering cost $= \dfrac{D}{Q^*} \times C_o = \dfrac{4000}{141.42} \times 100$

$= 2,828.43$

$=$

OM

~~Or~~ Carrying Cost or Holding cost

$$= \frac{Q^*}{2} \times C_h$$

$$= \frac{141.42}{2} \times 40$$

$$= 2828.43$$

$\therefore$ Total annual Cost $= 800,000 + 2828.43 + 2828.43$

$= $ Rs $805,656.85$/-

or $(TIC)_{at\ Q^*} = \sqrt{2DC_oC_h}$

$$= \sqrt{2 \times 4000 \times 100 \times 40}$$

$= $ Rs. 5656.85

* Here we have to add purchase cost as it is considered in this question.

$\therefore (TIC)_{at\ Q^*} = D \times C + \sqrt{2DC_oC_h}$

$= 800,000 + 5656.85$

$= $ Rs 805656.85/-

OM

(C) Saving due to switching from 1000 units (quantity) to EOQ unit

@ 1000 units = Q,

~~Ordering~~ purchase Cost = D × C

= 8,00000

Ordering cost = $\frac{D}{Q}$ Co

= $\frac{4000}{1000}$ × 100

= Rs 400/-

Holding cost = $\frac{Q}{2}$ × 40

= $\frac{1000}{2}$ × 40

= Rs 20,000.

∴ Total current annual cost

= 800,000 + 400 + 20,000

= 820,400 /-

∴ Savings = 8 20,400 − 805,656.85

= Rs 14,743.15

≃ 14743 per year

(ie ≃ 1.8% reduction)

OM

Model - 2

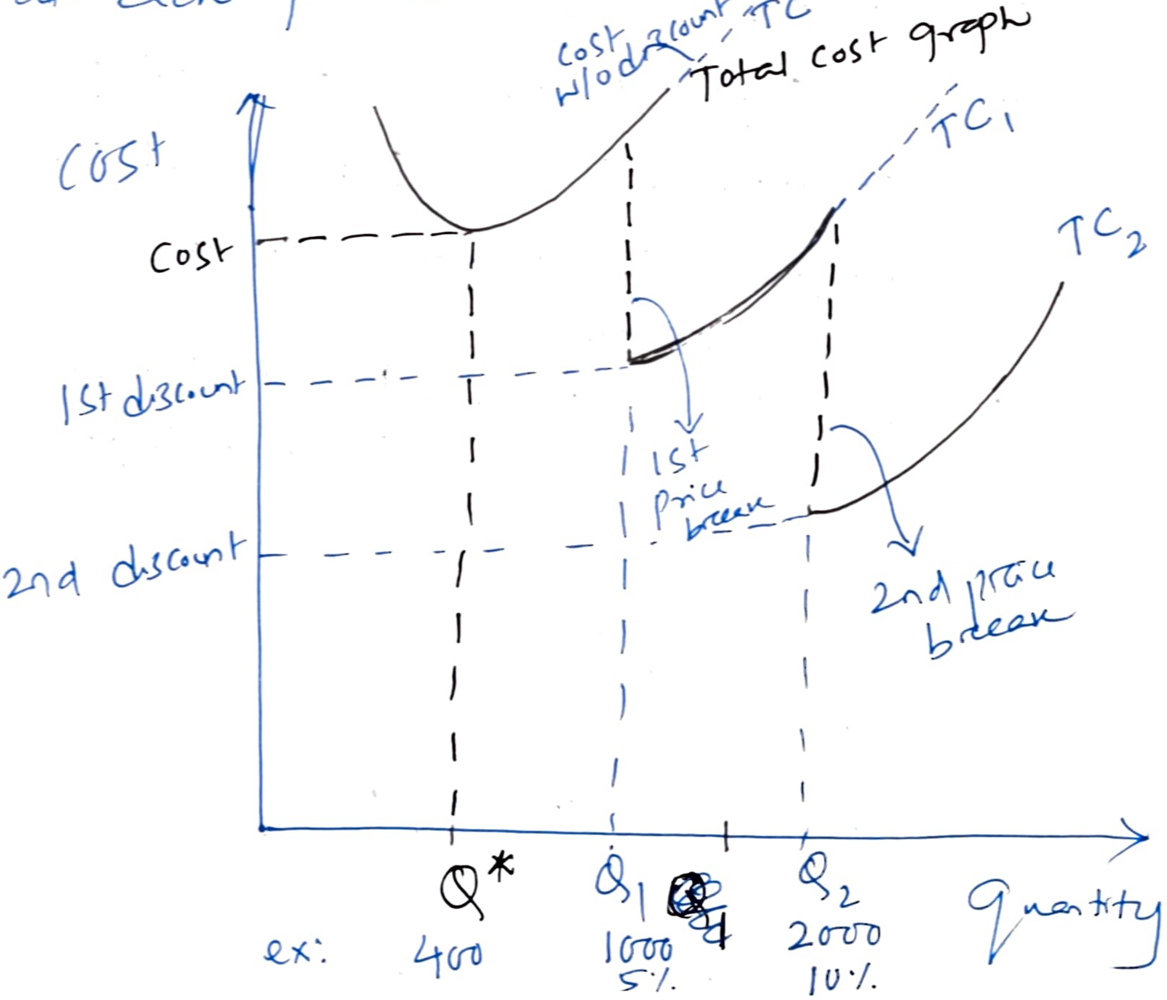
EOQ with price Break

OR Quantity discount model
or
Price break

available for or discount on → Unit cost of product

Main aim → Minimisation of inventory cost

For that we need to check the cost at each pt & also on EOQ.



Total cost = purchase cost + Ordering cost + Holding cost

Here we will include this as it is variable w.r.t to quantity of product

OM

$$TC = D \times C + \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

Annual demand for window frames is 10,000. Each frame costs Rs 200 and ordering cost is Rs 300 per order. Inventory holding cost is Rs 40 per frame per year. The supplier is willing to offer 2% discount of the order quantity is 1000 & 4% if the order quantity is 2000 or more. If the total cost is to be minimized, the retailer should

(a) Order 200 frames every year
(b) Accept 2% discount [✓ (c) Accept 4% discount]
(d) Order Economic order quantity

$D = 10,000$

$C = 200$ per frame

$C_o = 300$ /order

$C_h = 40$ / frame / year

Then

0 — 999 → 0% discount $C = 200$/fram

1000 – 1999 → 2% discount $C = 196$/fram

2000 & more → 4% discount $C = 192$/fra

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

$$= \sqrt{\frac{2 \times 10,000 \times 300}{40}}$$

$$Q^* = 388$$

Cost at EOQ ie Q^*

$$\underset{\text{at } Q^*}{T.C} = \underset{(RC)}{D.C} + \underset{(O.C)}{\frac{D}{Q} C_o} + \underset{(H.C)}{\frac{Q}{2} C_h}$$

at quantity ~~Q~~ 388 (ie within 0-999)

$$= 10000 \times 200 + \frac{10000}{388} \times 300 + \frac{388}{2} \times 40$$

$$\underset{\text{at } Q^*}{T.C} = 2015492 ₹$$

Next 1st discount at 1000 Unit.

$(T.C)_{\text{at } 1000}$ = we need to find out where 2% discount to thr for purchase cost ie each frame costs. ie here

$$\text{purchase cost } C = 200 - 200 \times 2\%$$

$$= 200 - 4$$

$$= 196 / \text{frame}$$

OM

$$(TC)_{\substack{\text{at 1000 unit} \\ -1999 \text{ unit}}} = D \cdot C + \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

$$= 10000 \times 196 + \frac{10000}{1000} \times 300 + \frac{1000}{2} \times 40$$

$$\Rightarrow TC(1000) = 1983000 ₹$$

3rd

2nd discount at 2000 unit on purchase cost is 4%.

$$\therefore C \text{ at } 2000 \text{ unit} = 200 - 200 \times 4\%$$

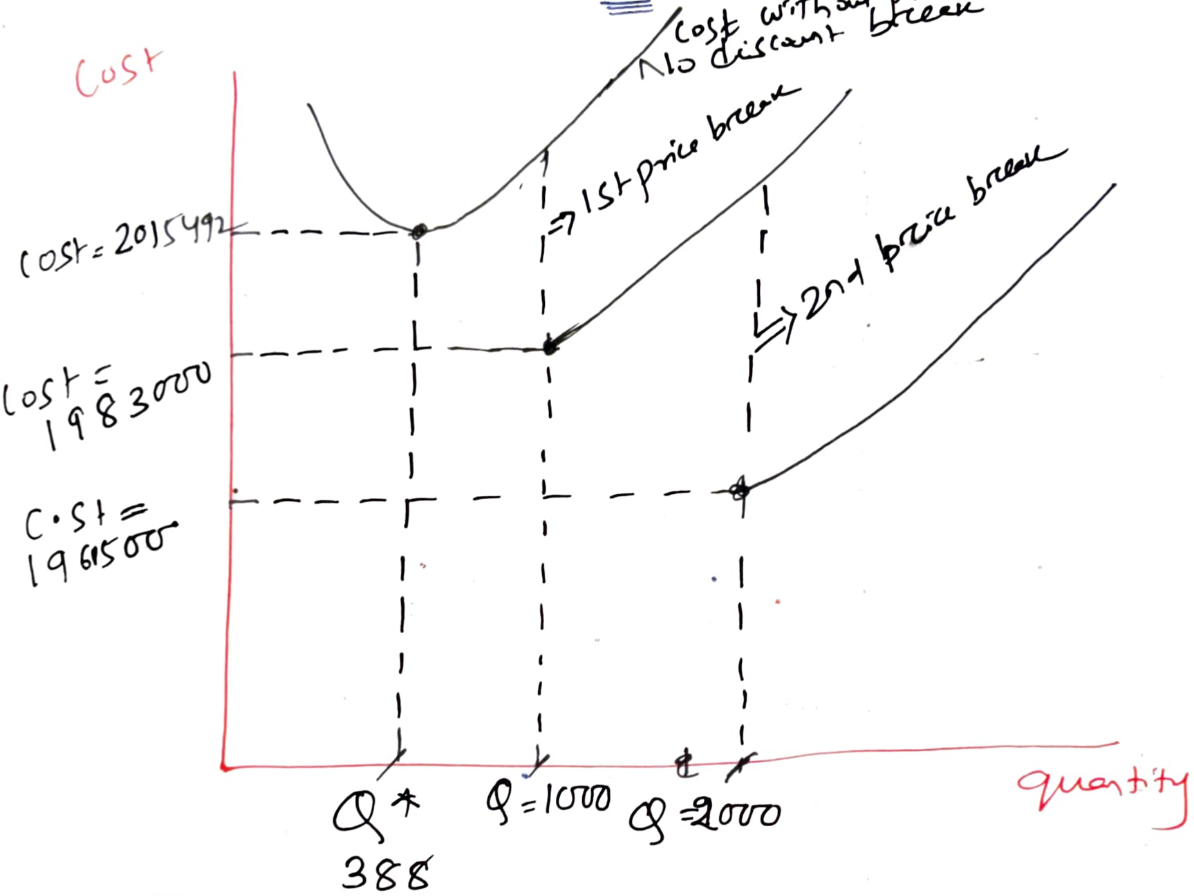
$$= 192 ₹/\text{frame}$$

$$\therefore (TC)_{2000} = D \cdot C + \frac{D}{Q} C_o + \frac{Q}{2} C_h$$

$$= 10000 * 192 + \frac{10000}{2000} \times 300 + \frac{2000}{2} \times 40$$

$$(TC)_{2000} = 1961500 ₹$$

$\therefore$ Out of three total costs minimum cost is seen at $(TC)_{2000}$ i.e at 4% discount. $\boxed{\text{Accept 4\% discount}}$

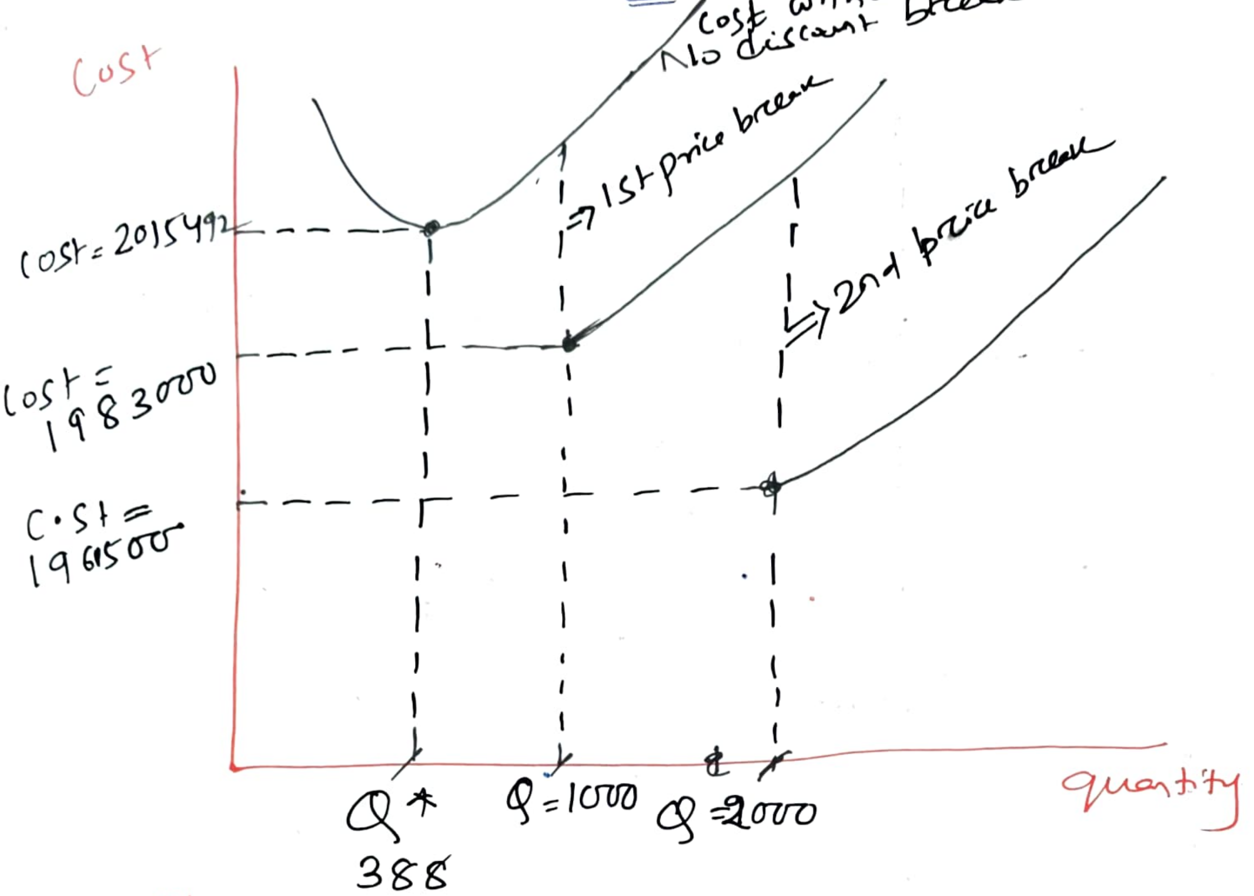


we will choose = 4% discount

Model-III Production / Buildup Model

Internally we produce the spare parts.

Here also we need to keep this as stock or inventory.



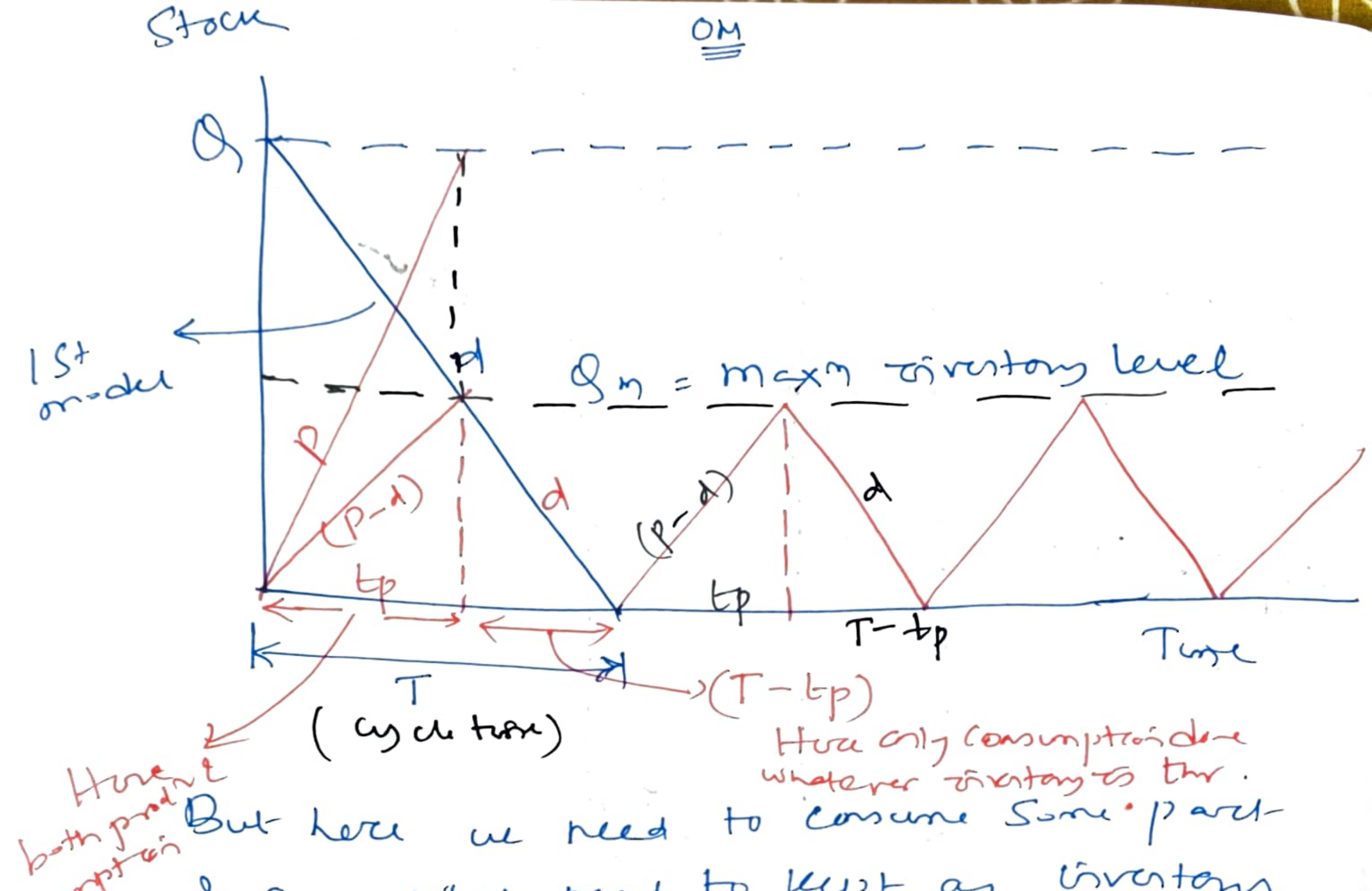
we will choose = 4 % discount

Model – III Production / Buildup Model

Internally we produce the spare parts.

Here also we need to keep this as stock or inventory.

OM



But here we need to consume some part & some what need to kept as inventory.

Instantaneously it cannot be filled up we need to produce this

tp = production time (tyre is produced & also consumed)

Let P = tyre is produced but no consumption occurred.

then if d = consumption rate

P−d is the inventory buildup or kept for further consumption or as stock.

OM

ex:-

Let $Q = 500$ maxm quantity

P = production rate = 25 units/day

$d = 10$ units / day.

Cycle time = 50 days = T

If no consumption then $t_p = 20$ days.

(i.e in 1 day → 25 unit
20 days → $25 \times 20 = 500$ unit) prodn

This is called Set up - cost

P = production rate

d = consumption rate

t_p = production + consumption

At t_p, Inventory built up rate = $p - d$

Inventory built up is gradual.

~~Ase~~ As consumption is also going on with prodn i.e $25 - 10 = 15$ units in a day is kept as inventory.

So in 20 days, $20 \times 15 = 300$ units is the maxm inventory level reached when both prodn & consumption going on.

After that, prodn stopped & only consumption is going on untill it reaching to Zero. Then this cycle continues as it is. $T - t_p$ = only consumption going on & in t_p ~~and~~. both prodn & consumption going on.

OM

Built up rate = $(P - d)$ /day

$T - t_p$ = only consumption with d unit /day.

In this model, no discount is available. So we will not consider purchase cost.

∴ Total inventory cost

$$= O.C + H.C$$

↳ Set up cost

Average Inventory

$$= \frac{\text{Area of } \Delta}{\text{Base}}$$

$$= \frac{\frac{1}{2} \times t_p Q_m + \frac{1}{2}(T - t_p) Q_m}{T}$$

$$Q_{avg} = \frac{Q_m}{2}$$

$$Q_m = (P - d) t_p$$

we can also write

~~tp~~ $P \times t_p = Q$

$$\Rightarrow \quad Q = t_p \times P$$

$$\boxed{Q_m = \frac{Q}{P}(P-d)}$$

maxm inventory level.

$$TIC = O.C + H.C$$

$$= \frac{D}{Q} C_o + \frac{Q_m}{2} C_h$$

$$= \frac{D}{Q} C_o + \frac{\frac{Q}{P}(P-d)}{2} C_h$$

$$\Rightarrow \boxed{TIC = \frac{D}{Q} C_o + \frac{Q}{2}\left(\frac{P-d}{P}\right) C_h}$$

After differentiation we get :-

$$\boxed{Q^* = \sqrt{\frac{2DC_o}{C_h}\left(\frac{P}{P-d}\right)}}$$

$\frac{P}{P-d} \Rightarrow$ Production factor

OM

Total inventory cost at Q^*

$$\boxed{TICQ^* = \sqrt{2DC_oC_h\left(\frac{P-d}{P}\right)}}$$

3rd model is better compared to 1st model.

$$\frac{P}{P-d} > 1$$

$$\frac{P-d}{P} < 1$$

Q-21 In m/c shop, pins of 15mm diameter are produced at a rate of 100 per month and the same is consumed at a rate of 500 per month. The production and consumption continue simultaneously till the maximum inventory is reached. Then inventory is allowed to reduce to zero due to consumption. The lot size of production is 1000. If backlog is not allowed, the maxm. inventory level is

$P = 1000$.

$D = 500$ $\quad\quad Q = 1000$

$$Q_m = Q \times \frac{(P-d)}{P}$$

$$= 1000 \frac{(1000 - 500)}{1000}$$

$Q_m = 500$ (option B)

Q.20 In computing Wilsons economic lotsize for an item, by mistake the demand rate estimate used was 40% higher than the true demand rates. Due to this error in the lot size computation. the total cost of setup plus inventory holding per unit time would rise above the true optimum by approximately (a) 1.4% (b) 3.3% (c) 18.3% (d) 8.7%.

$$D \Rightarrow 1.4 D$$

$$(TIC)_1 = \sqrt{2 D C_o C_h}$$

$$(TIC)_2 = \sqrt{2 \times (1.4 D) C_o C_h}$$

OM

$$\% \text{ Error} = \frac{(TIC)_2 - (TIC)_1}{(TIC)_1}$$

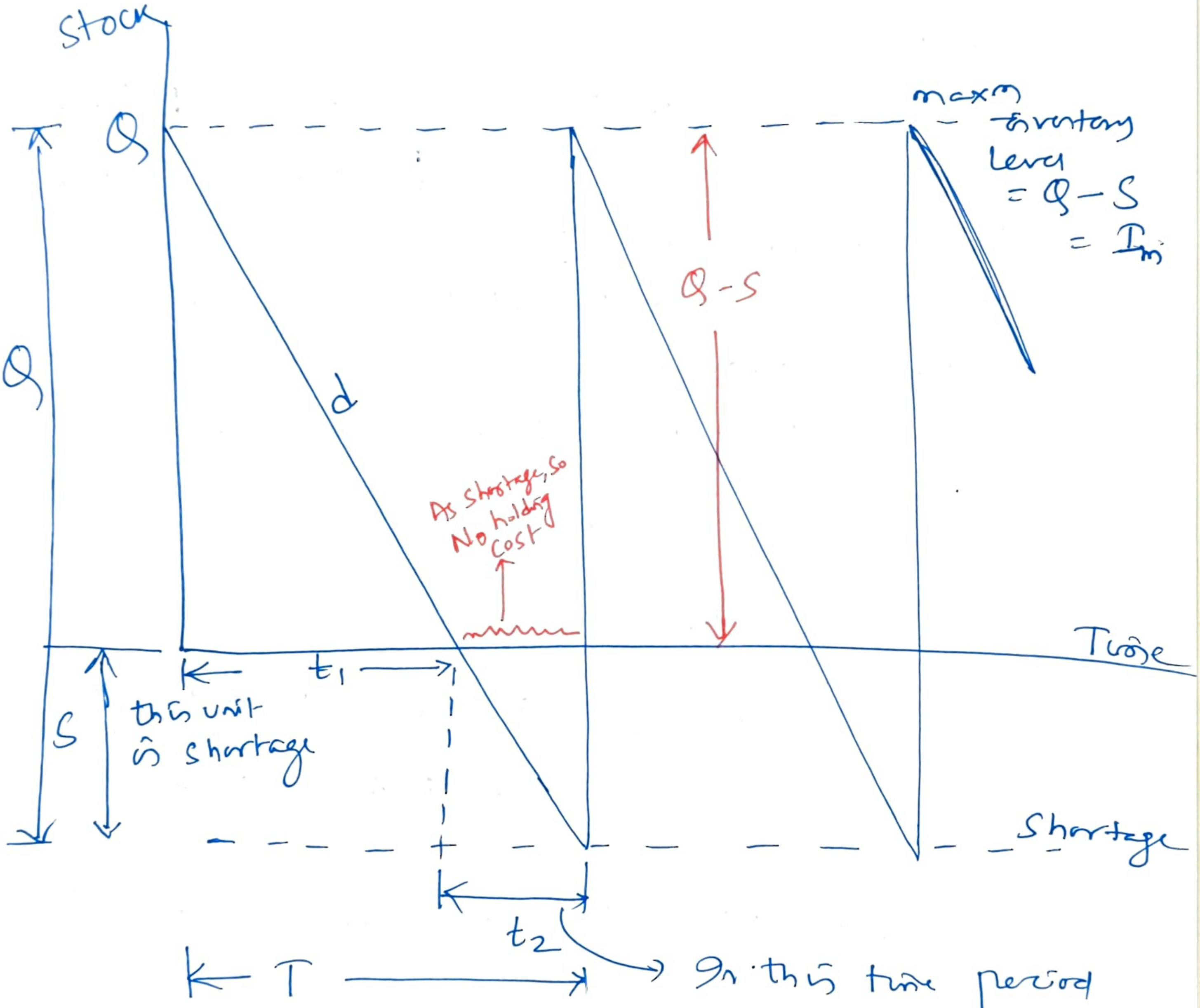
$$= 1.$$

$$= \frac{1.83\left(\sqrt{2DC_0C_h}\right) - \left(\sqrt{2DC_0C_h}\right)}{\sqrt{2DC_0C_h}}$$

$= 18.3\%$ option (C)

Model -4

Shortage or Back order model



S = No. of units shorts or back order

Total time = T

t_1 = we can fulfill the demand of customer

t_2 = we cannot fullfill the " " "

This type of model is only applicable where inventory holding cost is very high.

ex: BMW

Benifits:

(i) Cycle time is more (instead of T its $t_1 + t_2$)

so no. of order ↓ ordering cost ↓

(ii) Holding cost ↓

as time period is very less to hold the inventory

But shortage cost is added. here.

Here in this case:

S = No. of unit back order

C_b or C_s = Back order / Shortage cost per unit per year

Total cost = Ordering cost + Holding cost + Shortage cost or backorder cost

(Total inventory cost)

$$= \frac{D}{Q} C_0 + \cancel{\frac{Q}{2}} \left(\text{Average inventory} / \text{year} \times C_h \right)$$

$$+ \text{Average no. of units back order/year} \times C_b$$

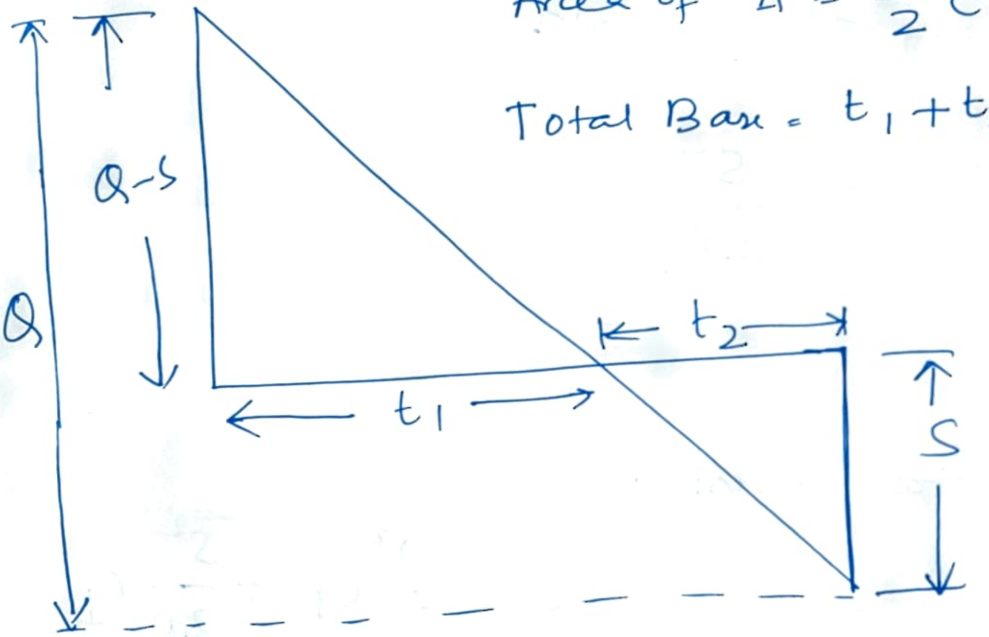
OM

$$Q_{avg} = \left(\underbrace{\frac{1}{2}(Q-S)\; t_1}_{\text{area of } \Delta}\right) \Big/ \text{Base}$$

$$= \frac{\frac{1}{2}(Q-S)\; t_1}{t_1 + t_2}$$

Area of Δ = $\frac{1}{2}(Q-S)\, t_1$

Total Base = $t_1 + t_2$



~~Qavg~~ Further with Similar Δ we can also write

$$\frac{t_1}{t_1+t_2} = \frac{Q-S}{Q}$$

∴ Q_{avg} becomes :

$$\boxed{Q_{avg} = \frac{(Q-S)^2}{2Q}}$$

OM

Average no of units short

$$S_{avg} = \frac{1}{2} \times S \times t_2 \Big/ t_1 + t_2$$

Similarly from similar Δ

$$\frac{t_2}{t_1+t_2} = \frac{S}{Q}$$

$$S_{avg} = \frac{1}{2} S \times \cancel{t_2} \frac{S}{Q}$$

$$\boxed{S_{avg} = \frac{S^2}{2Q}}$$

∴ Total inventory cost

$$\boxed{TIC = \frac{D}{Q} C_0 + \frac{(Q-S)^2}{2Q} C_h + \frac{S^2}{2Q} C_b}$$

Here two variables S & Q

We need to find optimum lot size & also optimum no. of units shortage.

After differentiation we will get

Optimum no. of unit order

$$\boxed{Q^* = \sqrt{\frac{2DC_o}{C_h} \times \frac{C_b + C_h}{C_b}}}$$

Total inventory cost at Q^*

$$\boxed{TIC_{at\ Q^*} = \sqrt{2DC_oC_h\left(\frac{C_b}{C_b + C_h}\right)}}$$

The factor

$$\left(\frac{C_b + C_h}{C_b}\right) > 1 \quad \text{or} \quad \frac{C_b}{C_b + C_h} < 1$$

as TIC value for this model is better than the model 1, so $\frac{C_b}{C_b + C_h} < 1$

Optimum no. of unit shorts (S^*)

$$\boxed{S^* = Q^*\left(\frac{C_h}{C_b + C_h}\right)}$$

Maxm inventory level

$$\boxed{M^* = Q^* - S^*}$$

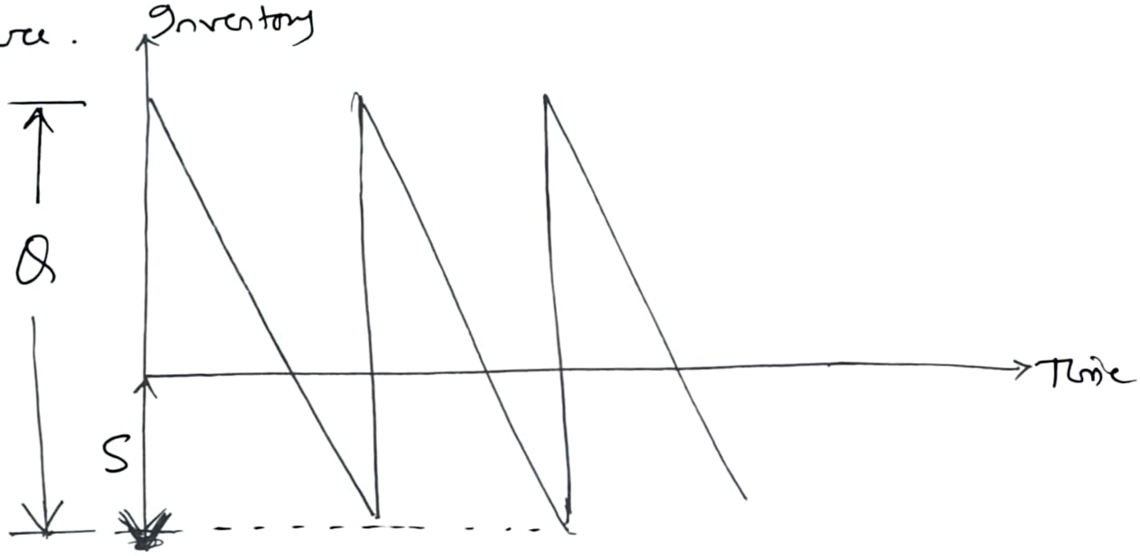
(or Im) $= Q^* - Q^*\left(\frac{C_h}{C_b + C_h}\right)$

$$\Rightarrow \boxed{M^* = Q^*\left(\frac{C_b}{C_h + C_b}\right)}$$

Another formula

$$\boxed{M^* = \sqrt{\frac{2DC_0}{C_h} \times \frac{C_b}{C_b + C_h}}}$$

Q.6 For a single item inventory system, the demand is continuous, which is 10,000 per year. The replacement is instantaneous and backorders (S units) per cycle are allowed as shown in the figure.



As soon as the quantity (Q units) ordered from the suppliers is received, the backordered quantity is ~~les~~ issued to the customers. The ordering cost is Rs 300 per order. The carrying cost is Rs 4 per unit per year. The cost of backordering is Rs 25 per unit per year. Based on the total cost minimization criteria, the maxm inventory reached in the system is ____. (round off to the nearest integer)

(GATE 2000)

$D = 10{,}000$ per year

$C_0 = 300$ per order

$C_h = 4$ / unit / year

$C_b = 25$ per unit per year.

$M^* = ?$

i.e $M^* = Q^* - S^*$

We know that direct formula is

$$M^* = \sqrt{\frac{2DC_o}{C_h} \times \frac{C_b}{C_b + C_h}}$$

$$= \sqrt{2 \times}$$

$= 1137.4$ (Ans)

If in this question, we don't remember the formula

$$Q^* = \sqrt{\frac{2DC_o}{C_h} \times \left(\frac{C_b + C_h}{C_b}\right)}$$

$=$

$\Rightarrow Q^* = 1319.09$ units.

$$S^* = Q^* \left(\frac{C_h}{C_b + C_h}\right)$$

Q4

$\Rightarrow \quad S^* = 181.94$

$M^* = Q^* - S^*$

$= 1319.09 - 181.94$

$= 1137.4$ (Ans)

OM

Probabilistic Model

In deterministic model
Demand & lead time both constant
But in Probabilistic model
In this case ⇒ Demand & lead time are not
constant.

⇒ Safety stock provide.

Service level ⇑ of safety stock is thr.

Demand and Profit model ⇒

or Static inventory model ⇒

This model is applicable where
items are outdated.
ex :- Fashion item. Fruit, vegetables.

ex :- Newspaper

D ⇒ Market Demand

S ⇒ Supply.

Case I

(D − S) ⇒ Under supply or Under demand

Loss = Profit × (D − S)

Case II

$S - D \Rightarrow$ Over supply or Under demand

$$\text{Loss} \equiv \text{Loss} \times (S - D)$$

In both cases loss appears.

So here we apply probabilistic model

~~P(S)~~

$$\boxed{P(S-1) < \frac{P}{P+L} \leq P(S)}$$

Commulative probability of $(S-1)$ units.

Commulative probability of S units.

P = Profit

L = Loss.

$$\boxed{P(S-1) < \frac{C_b}{C_b + C_h} \leq P(S)}$$

C_b = backorder cost/unit/year

C_h = Holding cost/Unit/year

OM

Q-19 A stockist wishes to optimize the number of perishable items he needs to stock in any month in his store. The demand distribution for this perishable item is :

Demand (in units)	2	3	4	5
Probability	0.10	0.35	0.35	0.20

The stockist pays Rs 70 for each item and he sells each at Rs 90. If the stock is left unsold in any month, he can sell the item at Rs 50 each. There is no ~~plenty~~ penalty for unfulfilled demand. To maximize the expected profit, the optimal stock level is

(a) 5 units (b) 4 units (c) 3 units (d) 2 units.

Profit = 90 − 70 = 20 ₹

Loss = 70 − 50 = 20 ₹

Demand	Probability	Commulative probability
2	0.10	0.10
3	0.35	0.45
		0.5
4	0.35	0.80
5	0.20	1.0

$$P(S-1) < \frac{P}{P+L} \leq P(S)$$

$$P(S-1) < \frac{20}{20+20} \leq P(S)$$

$$P(S-1) < 0.5 \leq P(S)$$

0.5 lies in between demand 3 & demand 4

$$P(4-1) < 0.5 < P(4)$$

No. of units (optimum) ⇒ 4

$S = 4$

OM

Inventory Control

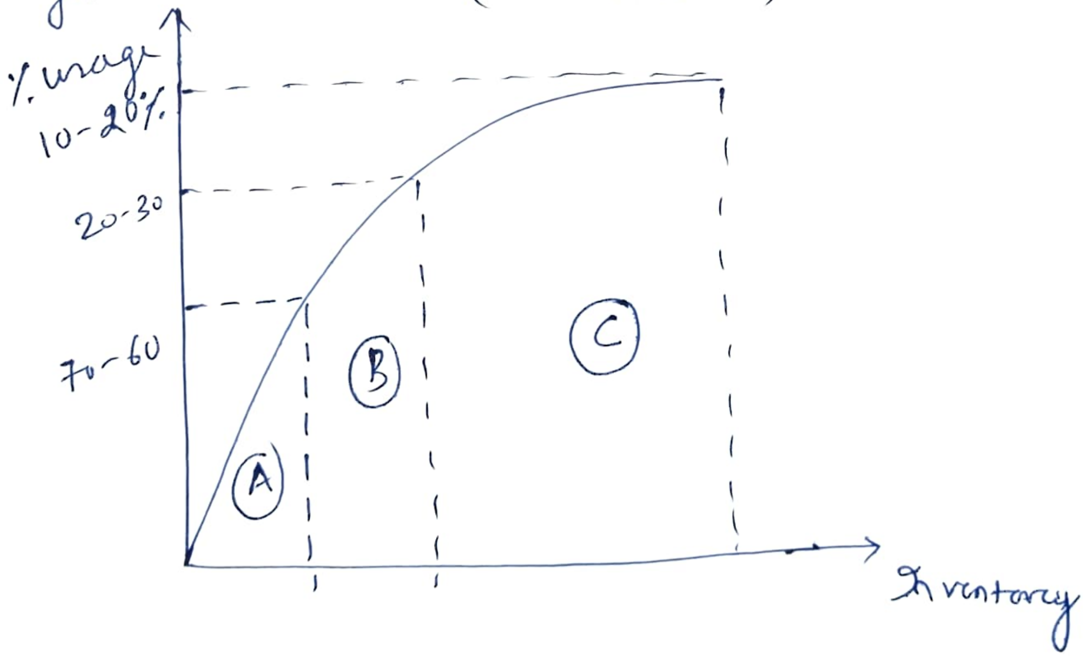
ABC control → divided according to % usage & cost

	Inventory	%age usages
Catagory/ Item A	10 - 20%	60 - 70% → frequent review very tightly control item
Catagory B	20 - 30%	20 - 30% → Tightly control.
Catagory C	60 - 70%	10 - 20% → Normal control

Scientist Parceto curve (80 - 20) curve

20% inventory item consists of 80% of financial budget.

(Parceto curve)



OM

Company No.	Cost/Product	No. of Unit usages	Total Cost	% usage
1	100	1000	10^5 ₹	$\frac{10^5}{\Sigma}$
2	10,000	1000	10^7 ₹	
3	5000	500	2500000	
4	500	300	150,000	

$$\frac{}{\sum_{\text{allocated}} \text{Total cost of inventory purchased}}$$

Inventory Management Techniques: ABC, VED, FSN and JIT

Inventory management refers to the systematic control of materials such as raw materials, work-in-process and finished goods to ensure uninterrupted production at minimum cost. Since inventories involve huge capital investment, scientific techniques are required to control them efficiently. Commonly used inventory management techniques include **ABC analysis, VED analysis, FSN analysis and Just-in-Time (JIT)**. Each technique focuses on a different dimension such as cost, criticality, movement and timing.

ABC Analysis (Always Better Control)

ABC analysis is based on the **Pareto principle (80–20 rule)**, which states that a small percentage of items accounts for a large percentage of inventory value. Items are classified according to their **annual consumption value**.

Annual Consumption Value = Annual demand × Unit cost

Classification

- **A items**

  Small in number but very high in value. They require tight control, accurate forecasting and frequent review.

- **B items**

  Moderate in number and value. These require reasonable control and periodic review.

- **C items**

  Large in number but low in value. Simple control methods and bulk purchasing are sufficient.

Control Policy

- A items: Top management control, low safety stock
- B items: Middle management control
- C items: Minimum control, higher safety stock

Advantages

- Better utilization of managerial efforts
- Reduction in inventory carrying cost
- Improved decision-making

Limitations

- Does not consider the **criticality** of items
- Low-value items may still be essential for production

VED Analysis

1. Introduction

VED Analysis is an important inventory control and classification technique used to prioritize materials, spare parts, and components based on their **criticality to**

operations.

The term **VED** stands for:

- **V – Vital**
- **E – Essential**
- **D – Desirable**

This method is widely used in manufacturing, maintenance engineering, hospitals, defense, supply chain management, and production planning. The objective is to ensure that highly critical items are always available while optimizing inventory cost.

2. Need for VED Analysis

Companies often handle thousands of items. All items do not have equal importance. Some items are critical for machine operation, while others are optional. VED analysis helps in:

- Avoiding stockouts of critical items
- Reducing machine downtime
- Improving reliability of systems
- Planning budgets intelligently
- Reducing idle inventory cost

Thus, VED is a **decision-making tool** for inventory prioritization.

3. Categories of VED Analysis

A. Vital (V) Items

- These items are absolutely critical for the functioning of a plant, machine, or system.
- Stockout leads to **complete breakdown**, high production loss, safety risks, and customer dissatisfaction.
- Must be stocked in sufficient quantity.
  Examples: Bearings of main motors, critical circuit breakers, turbine blades, ICU medical equipment.

B. Essential (E) Items

- Important items that affect performance but do not cause immediate shutdown.
- Delay can be tolerated for short periods, but not for long.

- Moderate monitoring required.

  Examples: Lubricants, secondary control relays, non-critical gaskets.

C. Desirable (D) Items

- Low criticality items used mainly for aesthetics, comfort, or non-core functions.
- Stockout does not disturb operations.
- Ordered only when required.

  Examples: Paints, covers, decorative panels, indicator bulbs.

4. Procedure of VED Analysis

1. **Identify all items or spare parts used in the system.**
2. **Assess the criticality** of each item based on:

    - Impact on machine downtime
    - Safety considerations
    - Replacement difficulty
    - Lead time and availability
3. **Classify each item** into V, E, or D category.
4. **Set inventory policies**:
    - High safety stock for Vital items
    - Moderate stock for Essential items
    - Minimal or no stock for Desirable items
5. **Review and update regularly** based on machine changes, failures, or operational priorities.

5. Applications of VED Analysis

- **Maintenance Engineering:** Spare part planning to avoid machine failures.
- **Production Management:** Ensuring smooth production flow.
- **Hospital Management:** Availability of life-saving medicines/equipment.
- **Supply Chain:** Efficient procurement planning.
- **Mechanical & Electrical Engineering:** Critical components identification.

6. Advantages of VED Analysis

- Ensures no shortage of critical items.
- Reduces machine downtime and increases productivity.
- Minimizes inventory carrying cost.
- Helps in efficient budgeting and resource allocation.

- Enhances reliability and safety of systems.
- Supports scientific decision-making.

Item Name	**Function**	**Criticality**	**V/E/D Category**
Motor Bearing	Main drive rotation	Very High	Vital
Lubricant Oil	Reduces friction	Medium	Essential
Display Panel	Shows values	Low	Desirable

VED analysis is an effective and systematic tool for classifying inventory based on criticality. It helps industries ensure the availability of important components while optimizing overall inventory cost. For engineering students, understanding VED analysis is essential for roles related to **production, maintenance, supply chain, and operations management**.

FSN Analysis (Fast–Slow–Non-moving)

FSN analysis classifies inventory based on **frequency of usage or movement** over a specific period.

Classification

- **Fast moving (F)**

  Frequently issued items with high turnover.
- **Slow moving (S)**

  Items used occasionally.

- **Non-moving (N)**

  Items not issued for a long time; may become obsolete.

Importance

- Helps in identifying **dead and obsolete stock**
- Supports effective warehouse space management

Advantages

- Reduction of inventory holding cost
- Improves stock utilization

Limitations

- Based on past consumption

- Seasonal demand variations may distort classification

JUST-IN-TIME (JIT) MANUFACTURING

1. Introduction

Just-In-Time (JIT) is a **production and inventory management philosophy** developed in Japan, primarily by Toyota.

The principle of JIT is simple:

"Produce the right item, in the right quantity, at the right time, with minimum waste."

It focuses on eliminating waste, reducing inventory, improving quality, and creating a smooth production flow. JIT is a core component of **Lean Manufacturing**.

2. Objectives of JIT

- To produce only what is needed, when it is needed.

- To eliminate non-value-adding activities (waste).
- To reduce inventory levels.
- To improve product quality and reliability.
- To enhance flexibility and responsiveness.
- To reduce production lead times.

3. Key Principles of JIT

(a) Elimination of Waste

JIT aims to remove the seven major wastes:

1. Overproduction
2. Waiting time
3. Transportation
4. Excess Inventory

5. Motion
6. Over-processing
7. Defects

(b) Continuous Improvement (Kaizen)

Small, incremental improvements to processes for efficiency and quality.

(c) Pull System

Production is based on **customer demand**, not forecasts. Workstations pull materials only when required.

(d) Small Lot Sizes

JIT prefers small batches for:

- Reduced inventory
- Faster detection of defects
- Quick response to changes

(e) High-quality Processes

Quality must be built **into the process**, not inspected at the end.

(f) Stable and Skilled Workforce

Workers must be trained in multiple skills and problem-solving.

(g) Reliable Suppliers

Frequent and timely deliveries from suppliers ensure smooth flow.

4. JIT Tools and Techniques

1. Kanban System

Visual signal (card, tag, board) used to trigger production and material movement.

Kaizen is a **Japanese philosophy** meaning **“continuous improvement.”** It focuses on making small, incremental improvements in processes, products, and work culture. Kaizen aims to remove waste, increase productivity, and create long-term organizational efficiency. It is widely used in **Lean Manufacturing, Total Quality Management (TQM), and Toyota Production System (TPS).**

Meaning of Kaizen

The word **Kai** means “change” and **Zen** means “for better.” Thus, Kaizen means **“change for the better”** or **“continuous betterment.”**

Kaizen is a mindset where employees at all levels—from workers to managers—contribute ideas regularly to improve efficiency.

Key Principles of Kaizen

1. Continuous Improvement

Improvement is never-ending; even small changes make a big difference over time.

2. Elimination of Waste (Muda)

Reducing the seven wastes:

- Overproduction
- Waiting
- Transportation
- Extra processing

- Defects
- Motion
- Over inventory

3. Involvement of Everyone

Employees are encouraged to suggest improvements through suggestion schemes, meetings, and workshops.

4. Standardization

Once improvement is successful, it becomes the new standard procedure.

5. Gemba Philosophy

“Go to the actual place” — managers observe processes directly at the shop floor before making decisions.

6. Teamwork

Improvement is done through small teams, quality circles, and cross-functional groups.

Kaizen Cycle (PDCA Cycle)

Kaizen uses the **PDCA cycle**, which includes:

P – Plan

Identify a problem, collect data, and plan for change.

D – Do

Implement the change on a small scale.

C – Check

Analyze results and compare them with the target.

A – Act

Standardize the improved method or adjust and repeat the cycle.

This cycle promotes systematic and continuous improvement.

Tools Used in Kaizen

Kaizen relies on several tools such as:

- **5S Method:** Sort, Set in order, Shine, Standardize, Sustain
- **Value Stream Mapping (VSM)**
- **Root Cause Analysis (RCA)**
- **Fishbone Diagram**
- **Pareto Chart**

- **Standard Operating Procedures (SOPs)**
- **Kanban boards**
- **Checklists and visual controls**

Benefits of Kaizen

- Increased productivity
- Improved product quality
- Reduction in waste and cost
- Better employee morale and involvement
- Improved safety and workplace organization
- Shorter production time
- Enhanced teamwork and communication
- Builds a culture of continuous improvement

Limitations of Kaizen

- Requires long-term commitment
- Improvements are slow and incremental
- Employees may resist change
- Not effective without management support
- Results take time to become visible

Real Industry Example

Toyota uses Kaizen as the foundation of its production system.
Each employee suggests improvements regularly.
For example, small changes like redesigning tool arrangements reduced assembly time by 10–20%.

Such continuous small improvements made Toyota one of the world’s most efficient manufacturing companies.

Kaizen is a powerful and practical system of continuous improvement. It encourages small, daily changes that collectively bring major benefits over time. For B.Tech students, understanding Kaizen is essential for careers in manufacturing, production engineering, industrial engineering, and quality management.

2. 5S System

A workplace organization method:

- Sort
- Set in Order
- Shine

- Standardize
- Sustain

3. SMED (Single Minute Exchange of Die)

Reduces setup time to single-digit minutes.

4. Total Productive Maintenance (TPM)

Ensures that machines run with zero breakdowns and zero defects.

5. Poka-Yoke

Mistake-proofing techniques to prevent errors.

5. Advantages of JIT

- Reduced inventory cost

- Lower storage and handling cost
- Improved product quality
- Reduced waste and defects
- Higher productivity
- Greater customer satisfaction
- Faster production and delivery
- Better supplier relationships

6. Limitations of JIT

- Highly dependent on reliable suppliers
- Any disruption (strikes, transport delays) stops production
- Requires trained workforce
- Not suitable for highly volatile demand

- High initial cost of implementation

7. JIT in Toyota – A Real Example

Toyota uses a **Kanban-based JIT system** where every workstation produces only when the next process demands. This eliminates overproduction, keeps inventory low, ensures high quality, and makes Toyota one of the most efficient automotive manufacturers in the world.

Just-In-Time is a powerful production philosophy that focuses on waste elimination, continuous improvement, and demand-driven manufacturing. It ensures higher efficiency, reduced costs, and improved customer satisfaction.

KANBAN SYSTEM

1. Introduction

Kanban is a **visual scheduling and inventory control system** developed by Toyota as part of the **Toyota Production System (TPS)**. The word *Kanban* in Japanese means **“signboard” or “card.”** It uses visual signals (cards, tags, bins, or digital boards) to control the flow of materials and production based on **actual customer demand** instead of forecasts. Kanban is a key tool in **Lean Manufacturing** and **Just-In-Time (JIT)** systems.

2. Meaning and Concept

Kanban ensures that:

- materials are supplied **only when needed**,

- production happens **only when the next process demands**,
- inventory levels remain **minimum**.

It is a **pull-based system**, meaning production is triggered by demand from downstream processes.

3. Objectives of Kanban

- To control production quantity and timing
- To reduce excess inventory
- To eliminate overproduction (biggest waste)
- To maintain a continuous and smooth flow of materials
- To improve production flexibility and responsiveness
- To simplify communication between processes

4. How the Kanban System Works

Kanban typically uses **cards or signals** attached to containers, pallets, or products. When materials are consumed, the card is sent back as a signal to produce or supply more.

Basic Steps:

1. Workstation uses materials from a bin.
2. Empty bin + Kanban card is sent to the supplier/previous process.
3. The card acts as an **authorization to produce**.
4. Supplier restocks the bin and returns it with the card.
5. The cycle continues, ensuring flow without excess inventory.

5. Types of Kanban

1. Production Kanban (P-Kanban)

Authorizes the production of a specific quantity of items.

2. Withdrawal Kanban (W-Kanban)

Authorizes the movement/withdrawal of items from one process to another.

3. Supplier Kanban

Used to request raw materials from outside suppliers.

4. Emergency Kanban

Used when there is unexpected demand or defect.

5. Signal Kanban

Used in batch production to trigger large-lot manufacturing.

6. Rules of Kanban (Toyota’s Six Rules)

1. Downstream processes withdraw items only as needed.
2. Upstream processes produce only the quantity withdrawn.
3. Defective items are never sent downstream.
4. Kanban must always accompany the product.
5. Number of Kanban cards must be minimized.
6. Improve Kanban system continuously.

7. Benefits of Kanban

- Reduced inventory and storage cost
- Lower manufacturing lead time
- Improved process visibility and control
- Reduction in defects and waste

- Smooth production flow
- Faster response to customer demand
- Improved coordination between departments
- Encourages continuous improvement (Kaizen)

8. Limitations of Kanban

- Requires stable and predictable demand
- Highly dependent on reliable suppliers
- Any disruption halts the entire production
- Not suitable for highly customized or variable products
- Requires disciplined workforce and accurate data

9. Real Industry Example

Toyota uses Kanban cards for all components, from nuts and bolts to engines. When an assembly worker removes the last part from a bin, the Kanban card triggers the supplier to refill it.
This reduces inventory drastically while maintaining a smooth, uninterrupted production line.

Companies like **Honda, Ford, Dell, Amazon, and Walmart** also use Kanban to manage materials and logistics.

Kanban is a powerful visual tool for **work control, production scheduling, and inventory management**. It ensures that materials flow smoothly through the factory based on demand while minimizing waste. Mastering the Kanban system is crucial because it forms the backbone of **Lean Manufacturing and JIT production** in modern industries.

Difference Between Kaizen and Kanban System

Kaizen and Kanban are two important components of **Lean Manufacturing** and the **Toyota Production System**, but they serve different purposes. Kaizen focuses on **continuous improvement**, while Kanban focuses on **visual workflow and inventory control**.

1. Meaning

- **Kaizen:** A Japanese philosophy meaning *continuous improvement* through small, incremental changes.
- **Kanban:** A visual signaling system used to manage workflow and control inventory based on demand.

2. Focus Area

- **Kaizen:** Improving processes, quality, productivity, and eliminating waste.
- **Kanban:** Managing the flow of materials and information using a “pull system.”

3. Objective

- **Kaizen:** To create a culture of continuous improvement involving all employees.
- **Kanban:** To control production and inventory levels and avoid overproduction.

4. Nature

- **Kaizen:** Philosophical and cultural; long-term mindset.
- **Kanban:** Operational and tactical; day-to-day production control tool.

5. Implementation Method

- **Kaizen:** Done through Kaizen events, PDCA cycle, 5S, root cause analysis, and teamwork.
- **Kanban:** Implemented using cards, bins, boards, signals, and rules to regulate production.

6. Tools Used

- **Kaizen:** 5S, Value Stream Mapping, Pareto Chart, Fishbone Diagram, PDCA.
- **Kanban:** Kanban cards, bins, Kanban boards, pull signals.

7. Impact

- **Kaizen:** Improves quality, reduces waste, increases employee involvement.
- **Kanban:** Reduces inventory, smoothens production flow, improves scheduling.

8. Worker Involvement

- **Kaizen:** Involves all employees at all levels in improvement activities.
- **Kanban:** Involves mainly operators and supervisors for material flow control.

9. Time Frame

- **Kaizen:** Long-term and continuous.
- **Kanban:** Real-time and continuous during production.

10. Outcome

- **Kaizen:** Better processes and work culture.
- **Kanban:** Optimized production scheduling and minimal inventory.

Comparison

Basis of Difference	**Kaizen**	**Kanban**
Meaning	Continuous improvement philosophy	Visual workflow & inventory control system
Purpose	Improve processes and eliminate waste	Maintain smooth flow using pull system
Nature	Cultural and long-term	Operational and short-term
Focus	Process improvement	Production scheduling & inventory

Implementation	PDCA, 5S, teamwork	Cards, boards, bins, signals
Employee Involvement	All levels of employees	Mainly operators & supervisors
Output	Improved productivity & quality	Reduced inventory & lead time
Core Principle	Small, continuous improvements	Produce only when demanded
Type of System	Management philosophy	Material control technique
Example	Reducing setup time through Kaizen	Using Kanban cards to request materials

Kaizen builds a culture of continuous improvement, while Kanban ensures smooth, demand-driven production. Both systems complement each other in Lean Manufacturing but serve different roles—Kaizen improves the process, and Kanban controls the flow.

Inventory management techniques such as ABC, VED, FSN and JIT play a vital role in reducing costs, ensuring availability of materials and improving operational efficiency. Each technique focuses on a different aspect of inventory control, and their combined application provides a comprehensive and effective inventory management system suitable for modern industrial environments.

Integration of Techniques

In practice, organizations often use a **combination of techniques**. For example:

- **ABC–VED matrix** is used to control high-value and critical items effectively.
- **FSN** helps identify obsolete items among ABC or VED classes.
- **JIT** complements these techniques by minimizing overall inventory levels.

Introduction to ERP Systems and Production Modules

Enterprise Resource Planning (ERP) is an integrated information system that enables organizations to manage and coordinate all business processes using a **single, centralized database**. ERP systems integrate functions such as production, procurement, inventory, finance, human resources, sales and quality management, thereby improving efficiency, transparency and decision-making. In production management, ERP plays a vital role in **planning, scheduling, controlling and monitoring manufacturing activities**.

What is an ERP System? ERP is a **software framework** that integrates various functional departments of an organization into a unified system. It ensures real-time information flow across departments, eliminating data duplication and improving operational control.

Key Characteristics of ERP

- Integrated and centralized database
- Modular architecture
- Real-time information processing
- Standardized business processes
- Scalability and flexibility

Objectives of ERP in Production

- Efficient planning and utilization of resources

- Reduction in production lead time
- Improved inventory and material control
- Accurate demand forecasting
- Enhanced coordination between departments

ERP Architecture

ERP systems generally consist of:

1. **Database layer** – Centralized data storage
2. **Application layer** – Business logic and processing
3. **User interface layer** – Interaction with end users

Production-Related ERP Module

1. Production Planning (PP) Module

The Production Planning module is the **core ERP module for manufacturing**.

Functions:

- Demand management and forecasting
- Master Production Scheduling (MPS)
- Material Requirements Planning (MRP)
- Capacity planning
- Production order creation and control

Benefits:

- Balanced demand and supply

- Reduced stock-outs and excess inventory

2. Materials Management (MM) Module

This module ensures **availability of materials** at the right time and quantity.

Functions:

- Procurement and vendor management
- Inventory management
- Goods receipt and issue
- Invoice verification

Benefits:

- Reduced material cost

- Improved supplier coordination

3. Inventory Management Module

Often integrated with MM and PP modules.

Functions:

- Stock level monitoring
- ABC, VED, FSN analysis
- Warehouse management
- Stock valuation

Benefits:

- Reduced carrying cost

- Improved inventory turnover

4. Shop Floor Control (SFC) Module

SFC focuses on **real-time monitoring of production activities**.

Functions:

- Work order tracking
- Machine and labor utilization
- Production progress reporting
- Bottleneck identification

Benefits:

- Improved production efficiency

- Better control over shop floor operations

5. Quality Management (QM) Module

This module integrates quality planning and control with production.

Functions:

- Incoming material inspection
- In-process and final inspection
- Quality documentation and reporting
- Corrective and preventive actions

Benefits:

- Improved product quality

- Reduced rework and rejection

6. Plant Maintenance (PM) Module

Ensures reliable operation of production equipment.

Functions:

- Preventive and breakdown maintenance
- Equipment history tracking
- Maintenance scheduling
- Spare parts management

Benefits:

- Reduced downtime

- Increased equipment life

7. Sales and Distribution (SD) – Production Link

Though not a core production module, SD provides **demand input** to production planning.

Functions:

- Customer order processing
- Delivery scheduling
- Demand forecasting

Integration of ERP Production Modules

All production-related modules are **fully integrated**:

- SD provides demand → PP plans production
- PP generates material requirements → MM procures materials
- SFC executes production → QM checks quality
- PM maintains machines → Ensures uninterrupted production

This integration leads to **smooth and coordinated manufacturing operations**.

Advantages of ERP in Production

- Improved production planning accuracy
- Reduced lead time and WIP inventory
- Enhanced visibility and control
- Better coordination among departments
- Data-driven decision making

Limitations of ERP

- High implementation cost
- Time-consuming customization
- Requires employee training and change management
- Dependence on accurate data entry

ERP systems play a crucial role in modern production management by integrating planning, execution and control functions. Through various production-related modules such as PP, MM, Inventory, SFC, QM and PM, ERP enables organizations to achieve **efficient resource utilization, cost reduction and improved customer satisfaction**. Successful implementation of ERP leads to enhanced productivity and competitiveness in today's dynamic manufacturing environment.

Maintenance Strategies: Preventive, Predictive and Breakdown maintenance

Equipment is an important resource which is constantly used for adding value to products. So it must be kept at the best operating condition. Otherwise, there will be excessive down time and also interruption of production if it used in a mass production line. Poor working of equipment's will lead to quality related problems. Hence it is an absolute necessity to maintain the equipment's in good operating conditions with economical cost. Hence, we need an integrated approach to minimize the cost of maintenance. In certain cases, the equipment will be obsolete over a period of time. If a firm wants to be in the same business competitively, it has to take decision on whether to replace the equipment or to retain the old equipment by taking the cost of maintenance and operation into account.

Maintenance Strategies

Maintenance strategies are systematic approaches adopted to ensure that equipment and facilities operate efficiently, safely, and reliably throughout their intended life. The three most commonly used strategies are Preventive Maintenance, Predictive Maintenance, and Breakdown (Corrective) Maintenance.

1. Preventive Maintenance (PM)

Preventive maintenance (PM) is the periodical inspection and service activities which are aimed to detect potential failures and perform minor adjustments or repairs which will prevent major operating problems in future.

Preventive maintenance is a planned and scheduled maintenance activity carried out at predetermined time intervals or usage levels to reduce the probability of equipment failure.

It is based on the assumption that equipment failure can be prevented by regular inspection, servicing, lubrication, and replacement of parts before breakdown occurs.

Key Activities

- Periodic inspection
- Cleaning and lubrication
- Adjustment and calibration
- Scheduled replacement of worn-out parts

Advantages

- Reduces unexpected breakdowns
- Improves equipment reliability and life
- Ensures consistent production quality
- Enhances safety and working conditions

Limitations

- May result in unnecessary maintenance
- Higher planned maintenance cost
- Requires proper scheduling and skilled manpower

Applications

- Production machines
- Power plants
- Automotive systems
- Manufacturing industries

2. Predictive Maintenance (PdM)

Predictive maintenance is a condition-based maintenance strategy in which maintenance is performed only when monitoring data indicates a potential failure.

This approach uses real-time data and diagnostic tools to predict when equipment failure is likely to occur, allowing maintenance just in time.

Techniques Used

- Vibration analysis
- Thermography (infrared analysis)
- Oil and wear debris analysis
- Ultrasonic testing
- Acoustic emission monitoring

Advantages

- Minimizes maintenance costs
- Avoids unnecessary preventive tasks
- Reduces downtime significantly

- Improves asset utilization

Limitations

- High initial investment
- Requires advanced monitoring equipment
- Skilled technical expertise needed

Applications

- Rotating machinery (motors, turbines)
- Critical process equipment
- Continuous process industries

3. Breakdown Maintenance (Corrective Maintenance)

Breakdown maintenance is the repair which is generally done after the equipment has attained down state. It is often of an emergency nature which will have associated penalty in terms of expediting cost of maintenance and down time cost of equipment’s.

Preventive maintenance will reduce such cost up to a point. Beyond that point, the cost of preventive maintenance will be more when compared to the down time cost. Under such situation, a firm can opt for break-down maintenance. These concepts are shown in Figure below.

Breakdown maintenance is a reactive maintenance strategy where maintenance is performed only after equipment failure occurs.

It follows a “run-to-failure” approach and is suitable when the cost of maintenance is less than the cost of preventive actions.

Key Characteristics

- No scheduled maintenance
- Repair or replacement after failure
- Emergency maintenance actions

Advantages

- Low initial maintenance cost
- Simple to manage
- No planning or monitoring required

Limitations

- High downtime and production loss
- Risk of severe equipment damage
- Safety hazards

- Unpredictable repair costs

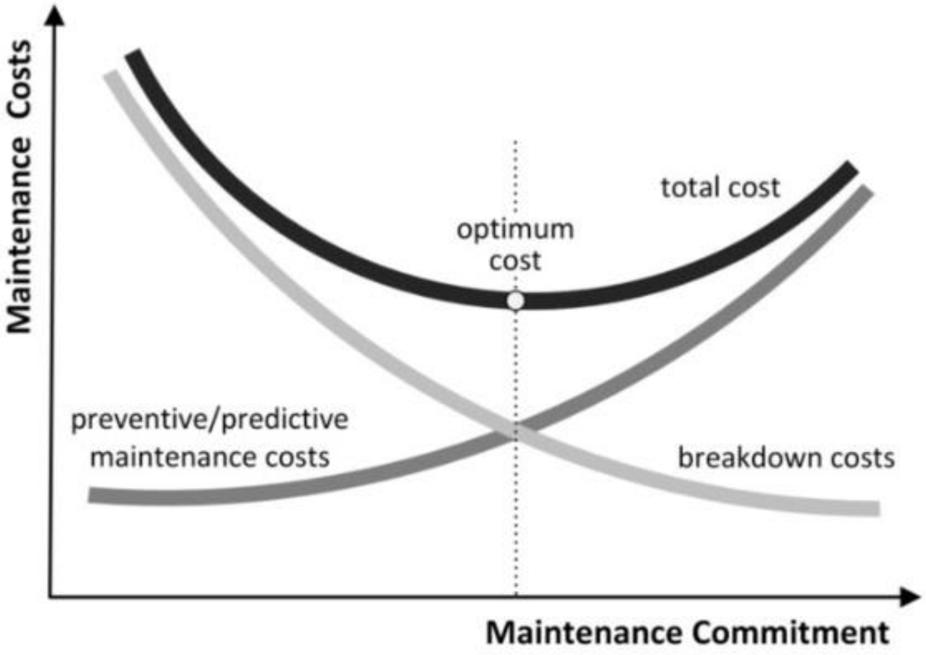
Applications

- Non-critical equipment
- Low-cost or easily replaceable items
- Light bulbs, small tools, fans

Aspect	Preventive Maintenance	Predictive Maintenance	Breakdown Maintenance
Nature	Planned & time-based	Condition-based	Reactive
Failure Prevention	Moderate	High	None
Cost	Medium	High initial, low long-term	Low initially, high later
Downtime	Low	Very low	High
Equipment Criticality	Medium to high	Very high	Low

An effective maintenance system often uses a combination of all three strategies depending on equipment criticality, cost, and operational importance.

- Preventive maintenance reduces failure probability.
- Predictive maintenance optimizes maintenance timing.
- Breakdown maintenance is economical for non-critical assets.



Introduction to Total Quality Management (TQM)

Nowadays, customers demand products/services with greater durability and reliability at the most economic price. This forces producers to strictly follow quality procedures right from design till shipment and installation of the products. So the goal of any competitive industry is to provide a product or service at the most economical costs, ensuring full customer satisfaction. This can be achieved through Total Quality Management (TQM); because quality is not a technical function, but a systemic process extending throughout all phases of the business, e.g., marketing, design, development, engineering, purchasing, production/operations.

As per Feigenbaum, it is an effective system for integrating the quality development, quality maintenance and quality improvement efforts of various groups in an organization so as to enable marketing, engineering, production and service at the most economical levels which allow for full customer satisfaction.

Scope of Total Quality Management

Total quality management guides the coordinated actions of people, machines and information to identify and fulfil customer quality requirements. The total quality management is applied to many stages of industrial cycle which are listed below:

Marketing

Engineering

Purchasing

Manufacturing

Mechanical

Shipping

Installation and product service.

Benefits of TQM

The benefits of TQM can be classified into the following two categories:

Customer satisfaction oriented benefits

Economic improvement oriented benefits

Customer satisfaction oriented benefits. The benefits under this category are listed below:

Improvement in product quality.

Improvement in product design.

Improvement in production flow.

Improvement in employee morale and quality consciousness.

Improvement in product service.

Improvement in market place acceptance.

Economic improvements oriented benefits.

The benefits under this category are as follows:

Reduction in operating costs.

Reductions in operating losses.

Reductions in field service costs.

Reductions in liability exposure.

Fundamental Factors Affecting Quality

The nine fundamental factors (9 M's) which are affecting the quality of products and services are: markets, money, management, men, motivation, materials, machines and mechanization, modern information methods and mounting product requirements.

(i) *Market:* Because of technology advancement, we could see many new products to satisfy customer wants. At the same time, the customer wants are also changing dynamically. So, it is the role of companies to identify needs and then meet it with existing technologies or by developing new technologies.

(ii) *Money:* The increased global competition necessitates huge outlays for new equipments and process. This should be rewarded by improved productivity.

This is possible by minimizing quality costs associated with the maintenance and improved of quality level.

(iii) *Management:* Because of the increased complex structure of business organization, the quality related responsibilities lie with persons at different levels in the organization.

(iv) *Men:* The rapid growth in technical knowledge leads to development of human resource with different specialization. This necessitates some groups like, System Engineering group to integrate the idea of all specialization.

(v) *Motivation:* If we fix the responsibility of achieving quality with each individual in the organization with proper motivation techniques, there will not be any problem in producing the designed quality products.

(vi) *Materials:* Selection of proper materials to meet the desired tolerance limit is also an important consideration. Quality attributes like surface finish, strength, diameter etc. can be obtained by proper selection of material.

(vii) *Machines and Mechanization:* In order to have quality products which will lead to higher productivity of any organization, we need to use advanced machines and mechanize various operations.

(viii) *Modern information methods:* The modern information methods help in storing and retrieving needed data for manufacturing, marketing and servicing.

(ix) *Mounting product requirements:* Product diversification to meet customers taste leads to intricacy in design, manufacturing and quality standards. Hence, companies should plan adequate system to tackle all these requirements.

Quality Control Activities During Product Cycle:

The quality control activities during production cycle can be classified into the following three categories:

New design control

Incoming materials control

Product control

New design control.

This has the following tasks:

Selling quality products

Engineering quality products

Planning quality products.

Incoming materials control.

This accounts for the following three tasks:

Buying quality materials

Receiving and inspecting quality materials.

Manufacturing quality parts and products.

Product control.

This involves the three important activities:

Inspecting and testing quality products.

Shipping quality products

Installing and servicing quality products.

Operating Quality Costs:

Quality cost in companies can be classified into the following two categories:

Cost of control

Costs of failure to control

Cost of control.

The costs of control can be divided into cost of prevention and cost of appraisal.

Costs of prevention. The costs incurred to avoid defects and nonconformities from occurring are accounted under cost of prevention. The following activities involve the costs of prevention.

- Quality planning
- Process control
- Design and development of quality information equipment
- Quality training and work force development
- Product-design verification

Cost of appraisal. Costs of maintain quality level by means of evaluation procedures like, inspection, test, quality audits, etc. are accounted under cost of appraisal. These are mentioned below:

- Test and inspection of purchased materials
- Laboratory acceptance testing
- Laboratory or other measurement services.
- Inspection

- Testing
- Checking labour
- Setup for test or inspection
- Test and inspection equipment and material and minor quality equipment
- Quality audits
- Maintenance and calibration of quality information test and inspection equipment
- Product engineering review and shipping release
- Field testing

Costs of failure to control.

These are nothing but the costs due to defects and nonconformities of products. This can be further classified into internal failure costs and external failure costs.

Cost of internal failure: Internal failure costs include costs which are incurred within the company such as scrap cost, spoilage cost, rework cost, material-procurement cost and factory contact engineering.

Cost of external failure. External failure costs are the costs due to unsatisfactory quality the company such as:

- Complaints in warranty
- Complaints out of warranty
- Product service
- Product liability

- Product recall.

Six Sigma

Six Sigma as a management standard in product variation (presently even for service variation) can be traced back to the work during 1920's when Walter Shewhart showed that three Sigma from the mean is the point where a process requires correction. Many measurement standards such as zero defects, later came into force but credit for coining the term "Six Sigma" goes to a Motorola engineer named Bill Smith. "Six Sigma" is a federally registered trade mark of Motorola.

In the early and mid 1980's, Motorola engineer felt that the traditional quality levels of measuring defects in thousands of opportunities did not provide enough depth of information. They decided to measure the defects per million opportunities. This helped Motorola to achieve bottom line results in their organization which resulted in a savings more than $16 million.

Since then, hundreds of companies around the world, most notably General Electric Company, have adopted Six Sigma as a way of doing business.

Definition. Six Sigma is a disciplined data-driven approach and methodology for eliminating defects which amounts to driving towards six standard deviations between the mean and the nearer specification limit in any process (manufacturing/transactional) of products/services. A Six Sigma defect is defined as any flaw that inhibits the attainment of customer expectations and specifications.

As defined by General Electric company, Six Sigma is a vision of quality which equates with only 3.4 defects per million opportunities for each product or service transaction and it strives for perfection.

Six Sigma level indicates that we are 99.99966% confident that the product/service delivered by us is defect free. This means that only 0.00034% of the times the product/service delivered is defect prone. When 0.0000034 is multiplied by one million, it comes to 3.4 defects per million opportunities (DPMO).

An "opportunity" is defined as a chance for nonconformance or not meeting the required specifications. This means that we need to be nearly flawless in executing our key processes.

$$\text{Actual Sigma level} = \frac{\text{Actual number of defects}}{\begin{array}{c}\text{Total number of opportunities for}\\ \text{the organization to make mistakes}\\ \text{from the customer angle}\end{array}} \times 100$$

A process is said to be at Six Sigma level provided that the process is not producing more than 3.4 defects per million opportunities.

The fundamental objective of Six Sigma methodology is the process improvement and reduction of variation through its application.

At its core, Six Sigma revolves around the following few concepts:

- It is critical to attributes which are most important to the customers.
- It focuses on the process more specifically what it can deliver.
- It aims for stability of the process which means that it ensures consistent and predictable processes to improve product quality which is the utmost expectation of the customer.
- It focuses on the design for Six Sigma to meet customer needs and process capability. Design for Six Sigma is a systematic methodology, utilizing tools, training and measurements, to enable us to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels.

18.10.1 Approaches for Six Sigma

There are two approaches for achieving Six Sigma which are as listed below:

- DMAIC
- DMADV

DMAIC. DMAIC means Define, Measure, Analyze, Improve and Control. The Six Sigma DMAIC process is an improvement system for existing processes falling below specification and looking for incremental improvement. It is systematic, scientific and fact based. This closed-loop process eliminates unproductive steps, often focuses on new measurements and applies technology for improvement.

DMADV. DMADV means Define, Measure, Analyze, Design, and Verify. The Six Sigma DMADV process is an improvement system used to develop new processes or products at Six Sigma quality levels. This can be used even for existing processes if they require more than just incremental improvement.

Both DMAIC and DMADV are executed by Six Sigma Green Belts and Six Sigma Black Belts and these are overseen by Six Sigma Master Black Belts.

Steps of Six Sigma DMAIC. As already mentioned, DMAIC means Define, Measure, Analyze, Improve and Control. These are explained in this section.

Step 1: Define

This step establishes a leadership team which will decide on the project on which it will work. It also identifies key considerations like, cost benefits, customer expectations, product quality enhancement and ability of the team to have a positive impact on the process. The specific actions of this step are listed below:

- Define all your products by making a list of them along with corresponding end results.
- Identify your customers of each end product, make assumptions about what they expect, survey customers to validate assumptions and select a product/project for continuous improvement process.

Step 2: Measure

In this step, the team examines all aspects of the project, develops a thorough understanding of it and identifies the critical requirements and processes. Once this is done, the team defines performance measures for key characteristics and establishes an effective means of measuring them. Then, the measurements of the process to determine current performances are done.

The sub-steps are as listed below:

- Define your needs in terms of essential inputs for products/projects selected.
- Set-up quality measures.
- Define the method of computing errors/unit, errors/million and actual Sigma level.
- Measure the current performance of the process.

Step 3: Analyze

In this step, the team analyzes the results of this collected data and lays the groundwork for improving the process. This analysis includes identification and quantification of the sources and locations of defect causing variables within the process.

These are achieved through defining the work process by flow charting existing process, identifying error/defect-producing steps and determining present error rate.

Step 4: Improve

In this step, the team performs the following.

- Identification of process improvements based on the collected data and analysis.
- Designing a plan of action.
- Performing risk assessments on the potential changes.
- Implementing the plan.
- Monitoring the results for the recommended changes.

The improvement of the work process can be achieved by doing the following:

- Lowering the probability of occurrence of mistakes by using suitable statistical quality control tools.
- Simplification of the process wherever possible.
- Elimination of non-value adding tasks.
- Highlighting the importance of Six Sigma and developing necessary skills.
- Flowcharting the revised process

Step 5: Control

In this step, the team reviews the entire process to ensure that the appropriate changes have been made and to identify the actions that will permanently maintain those changes. Further, steps are taken to control future process performance.

Steps of Six Sigma DMADV. The first three steps of DMAIC and DMADV are one and the same except the last two steps. The steps of DMADV are listed below. Though the first three steps of DMADV are same as that of DMAIC, they are fine-tuned with respect to application of Six Sigma to new products or services.

Step 1: Define the project goals and customer (internal and external) deliverables.

Step 2: Measure and determine customer needs and specifications.

Step 3: Analyze the process options to meet the customer needs.

Step 4: Design detailed process to meet the customer needs.

Step 5: Verify the design performance and ability to meet customer needs.

18.10.2 Types of Six Sigma Belts

The Six Sigma Belts are classified into the following categories:

- Green Belts
- Black Belts
- Master Black Belts

In addition to these belts, there is one more category known as Six Sigma Champions.

Green Belts. Six Sigma Green Belts are Six Sigma team leaders capable of forming and facilitating Six Sigma teams and managing Six Sigma projects from concept to completion. Typically, Green belt training consists of five days of classroom training and it is conducted in conjunction with Six Sigma team projects. Training covers facilitation techniques and management of meetings, project management, quality management tools, quality control tools, problem solving and exploratory data analysis. Their activities are centred around increasing customer satisfaction levels and business productivity. Green Belts are not full time positions. A Green Belt should be focusing on 1 to 2 projects. Usually, Black Belts help Green Belts in choosing their projects prior to the training, attend training with their Green Belts and assist them with their projects after the training.

The desirable skills of Green Belts are good problem solving ability, experience in leading a team, expertise in project management, competence to apply basic improvement tools, etc.

Black Belts. Six Sigma Black Belts are leaders of teams responsible for measuring, analyzing, improving and controlling key processes that influence customer satisfaction and/or productivity growth.

Black Belts are full time positions. They should focus on 1 to 3 projects. Direction and leadership for them should come from a Master Black Belt.

They are technical leaders who are technically oriented individuals held in high regard by their peers. They should be actively involved in the organizational change and development process. These candidates may come from a wide range of disciplines and need not be formally trained statisticians or engineers. However, because they are expected to master a wide variety of technical tools in a relatively short period of time, technical leader candidates will probably possess a background in college-level mathematics—the basic tool of quantitative analysis. College-level course work in statistical methods should be a prerequisite. Black Belts coach Green Belts and receive coaching and support from Master Black Belts.

The desirable skills of Black Belts are customer advocacy, self motivation, positive personality, good communication, project management expertise, technical aptitude, leadership, deep process knowledge, good problem solving ability, result orientation, etc.

Master Black Belts. Master Black Belts are the persons with highest level of technical and organizational proficiency. Because Master Black Belts train Black Belts, they should be sound on mathematical theory on which the statistical methods are based. They must be able to assist Black Belts in applying the methods correctly in unusual situations. Whenever possible, statistical training should be conducted only by Master Black Belts. If it is necessary for Black Belts and Green Belts to provide training, they should only do so under the guidance of Master Black Belts.

Because of the nature of the master's duties, communications and teaching skills should be considered as important as technical competence in selecting candidates. Master Black Belts are full time positions. The desirable skills of Master Black Belts are experience in different areas, analytical and technical competence, advanced statistical knowledge, ability to coach six sigma leaders.

Six Sigma Champions. In addition to different sigma belts, there is one more quality agent who also contributes to Six Sigma efforts, who is known as Six Sigma Champion.

Business leaders who lead Six Sigma by sponsoring projects are called "Champions". Champions are trained in the essentials of the Six Sigma methodology focusing on selecting the projects that are aligned with business goals. Champions must select and mentor Six Sigma project leaders called 'Belts". Champions must support, align and integrate the Six Sigma launch into their organizations.

18.10.3 Benefits of Six Sigma

The benefits of Six Sigma are as listed below:

- It ensures enhanced product quality.
- It enables predictable delivery of the products.
- It helps to achieve productivity improvement.
- It helps to have rapid response to changing needs of customers.
- It also facilitates the development and introduction of new products into the marketplace.

KAIZEN – CONTINUOUS IMPROVEMENT

Introduction

Kaizen is a Japanese management philosophy that emphasizes **continuous, incremental improvement** in all aspects of an organization. The word *Kaizen* is derived from two Japanese words:

- **Kai** – Change
- **Zen** – Better

Thus, Kaizen means **"change for the better."** It focuses on improving **processes, quality, productivity, cost, safety, and employee morale** through small, systematic improvements involving everyone.

Definition of Kaizen

Kaizen is a **continuous improvement approach** that involves all employees in identifying, analyzing, and implementing small improvements in processes to enhance overall organizational performance.

Philosophy and Principles of Kaizen

The core philosophy of Kaizen is based on the following principles:

1. **Continuous improvement** – Improvement is never-ending.
2. **Employee participation** – Every employee contributes ideas.
3. **Process orientation** – Focus on improving processes, not blaming people.
4. **Standardization** – Improved methods are standardized.
5. **Waste elimination** – Eliminate non–value-added activities (Muda).
6. **Customer focus** – Improvements aim at higher customer satisfaction.

Objectives of Kaizen

- Improve product **quality**
- Reduce **manufacturing cost**
- Increase **productivity**
- Improve **workplace safety**
- Reduce **defects and rework**
- Improve **employee involvement and morale**

Types of Kaizen

Point Kaizen

Small improvement at a **single workstation**.

Line Kaizen

Improvements across an **entire production line**.

System Kaizen

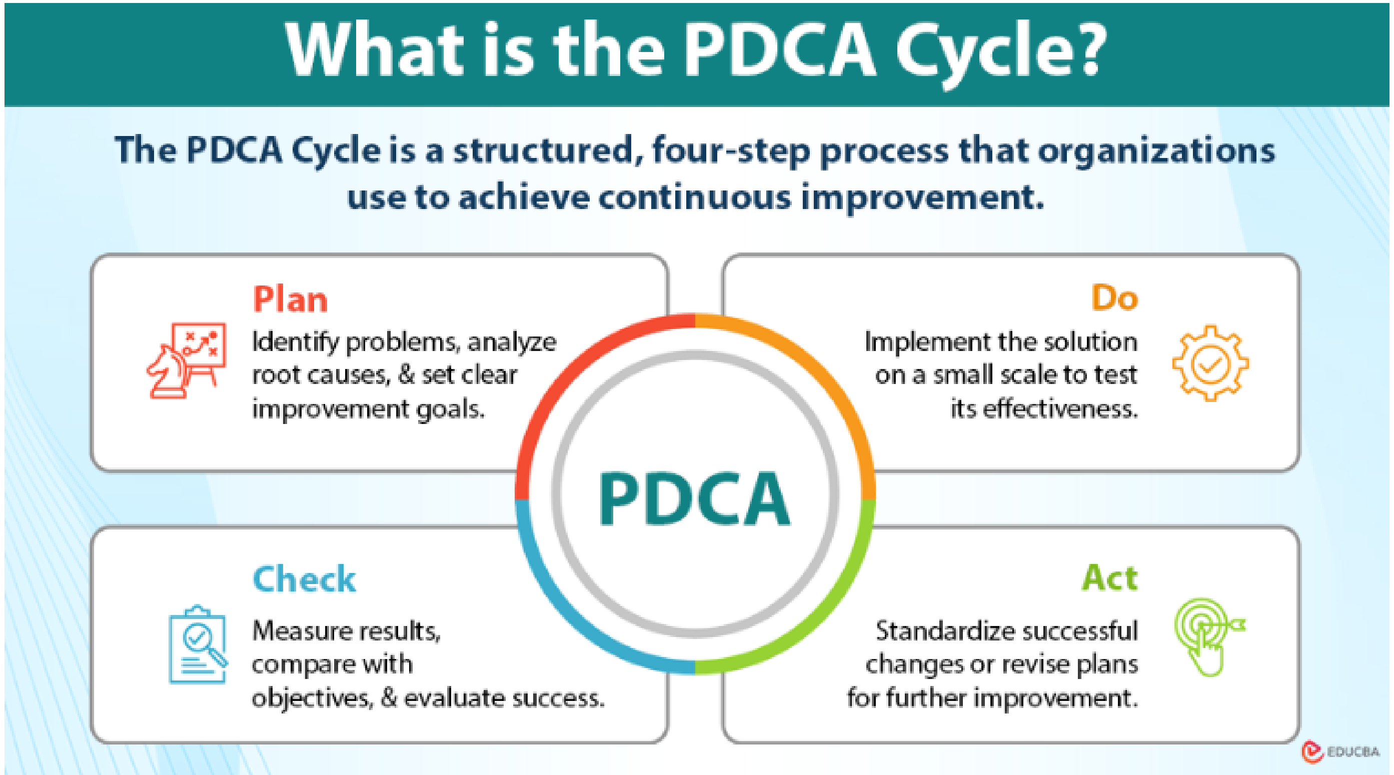
Improvements in **complete systems** such as inventory or logistics.

Kaizen Blitz (Event)

Short-term focused improvement activity (usually 3–5 days).

Kaizen Process – PDCA Cycle

PDCA Cycle Diagram



What is the PDCA Cycle?

The PDCA Cycle is a structured, four-step process that organizations use to achieve continuous improvement.

Plan
Identify problems, analyze root causes, & set clear improvement goals.

Do
Implement the solution on a small scale to test its effectiveness.

Check
Measure results, compare with objectives, & evaluate success.

Act
Standardize successful changes or revise plans for further improvement.

PDCA

EDUCBA

Explanation:

- **Plan**: Identify problem and propose improvement
- **Do**: Implement solution on a small scale
- **Check**: Measure and analyze results

- **Act**: Standardize successful improvements

Kaizen Tools and Techniques

5S System

The 5S system creates an organized workplace.

S	**Meaning**
Sort	Remove unnecessary items
Set in Order	Arrange items properly
Shine	Clean the workplace
Standardize	Establish standards
Sustain	Maintain discipline

5S Diagram

5S → Organized → Efficient → Safe → Productive Workplace

Quality Circles

Small groups of employees who meet regularly to identify and solve work-related problems.

Poka-Yoke (Mistake Proofing)

Devices or methods that prevent errors before they occur.

Example:

- Electrical plug that fits only in one direction.

Waste (Muda) in Kaizen

Kaizen aims to eliminate **7 wastes**:

1. Overproduction
2. Waiting
3. Transportation

4. Over-processing
5. Inventory
6. Motion
7. Defects

Waste Reduction Diagram

Input → Process → Output
↑
Waste
(Removed by Kaizen)

Kaizen in Manufacturing – Example

Example: Reducing Setup Time

Problem: Machine setup time = 60 minutes
Kaizen Action:

- Organize tools (5S)
- Standardize setup steps

- Train operators

Result:

- Setup time reduced to 35 minutes
- Increased machine utilization
- Reduced production cost

Kaizen vs Innovation

Kaizen	**Innovation**
Small improvements	Major changes
Continuous	One-time
Low cost	High cost
Involves all employees	Involves experts
Low risk	High risk

Advantages of Kaizen

- Continuous quality improvement
- Reduced cost and waste
- Increased productivity
- Improved teamwork
- Sustainable long-term improvement

Limitations of Kaizen

- Slow results for major changes
- Requires cultural commitment
- Less effective without management support

Kaizen is a powerful philosophy that promotes continuous improvement through employee involvement and systematic problem-solving**.** By focusing on small, incremental changes, organizations can achieve long-term excellence in quality, productivity, and competitiveness**.**

Lean Manufacturing

Lean manufacturing is a systematic approach to identify and eliminate wastes of all non-value added activities through continuous improvement that is being adopted by world class, high performance firms to produce remarkable results. It is also called as a manufacturing system in which friction is absent. Masaaki Imai calls this friction as muda (waste) which consists of all non-value-adding activities.

Global competition is forcing companies to improve quality, reduce delivery time and lower costs. The traditional manufacturing way of thinking has been "Cost + Profit = Selling Price". But, in the competing global environment, customers more or less influence the selling price of a product. Hence, the lean way of thinking is "Selling Price – Cost = Profit". Under this redefined scenario, the only way to survive in the market is to decrease cost by eliminating all forms of wastes.

The essence of lean manufacturing is to compress the time from the receipt of an order to the receipt of payment for that order.

In specific terms, lean manufacturing achieves the following:

- Reduction in cycle times
- On time deliveries
- Reduction in work-in-process inventory
- Improvement in quality
- Increase in the availability of machines
- Reduction in scrap/rework

Lean manufacturing which is often called *Just in Time* (JIT) or *Agile Manufacturing* is an operating strategy that seeks to maximize operational effectiveness by creating value in the eyes of the end customers. The focus is not on a department, area or process, but on the optimization of the entire value stream which is the series of processes between receipt of customer order and delivery of finished product.

Steps of Lean Manufacturing

The steps of lean manufacturing are as listed below:

(i) Precisely *specify value* by specific product
(ii) Identify the *value stream* for each product
(iii) Make the *value flow* without interceptions
(iv) Let the customer *pull* value from the producer
(v) Pursue *perfection*

(i) Specify value. Value is defined by the customer and is only meaningful when expressed in terms of a specific product, which means the customers' needs at a specific price and at a specific time. So, the value from the perspective of the final customer should be specified.

(ii) Identify value stream. The value stream is all the steps and processes required to bring a specific product, from raw materials to finished product, in the hands of the customers. Analyzing the entire flow of a product will almost reveal enormous amount of waste and non-value-adding sequences. This is frequently referred to as process reengineering.

The value stream analysis will always show three types of actions which occur along the value stream, as listed below:

- Steps that create value
- Steps that create no value but they are unavoidable due to current technologies or production methods or assets
- Steps that create no value and they are avoidable

So, a map of the value stream should be identified.

(iii) Make value flow. The value flow is a flow of raw materials through a dedicated arrangement of facilities with distinct value addition at each stage of the value stream, to produce products continuously which may result in less cost, decreased delivery time and other benefits of lean system, though other types of production are possible. So, make the value flow without interceptions.

(iv) Pull. Pull is defined as designing the production system based on customer needs. Here, customers pull their required product from a producer as and when they need that product. The implementation of value stream automatically reduces the product lead time to a greater extent. This enables the producers to provide the products as and when they are needed by the customers which helps the customer to pull their products on their necessity for those products. So, the value stream and pull are complementary to each other.

(v) Perfection. Perfection is defined as achieving all the required system performance measures at the highest levels. If an organization begins to accurately specify value, identify the entire value stream, and make the value-added steps for specific enterprise, achieving perfection is trivial.

Components of Lean Manufacturing

The components of lean manufacturing are as listed below:

1. Standardized production. This production involves setting, documenting and maintaining standards for three major areas of production.

- Cycle time (the time within which each operator has to complete a given task or tasks)
- Work process (layout of work area, required tools/equipments and steps/sequences)
- Work-in-process (daily number of units or pieces required in between workstations for a smooth operational flow)

To maintain standardized production, lean manufacturing rely heavily on documentation. This documentation is typically posted at all workstations and constantly revised to reflect current procedures and processes.

2. Continuous improvement (Kaizen) as explained earlier.

3. Just-in-Time (JIT) production. In this type of production, as explained at the beginning of this chapter, each station makes only the item in the required quantity when it is needed.

4. Design for manufacturing (DFM). In a product, after careful examination, all useless parts should be eliminated and the parts which are retained/newly designed and added in that product must be easily made with the existing infrastructure of the company or its supplier firms.

5. ***Poka yoke (Error-proofing).*** As explained earlier.

6. ***Cellular manufacturing.*** As explained in Chapter 6.

7. ***Single-Minute Exchange Die (SMED).*** This enables the operator to minimize the setting time and also the processing times on a machine with the aid of jigs and fixtures. The jigs and fixtures will facilitate the operator to load more than one component on a machine or to drill more than one hole simultaneously on the job mounted on a machine.

8. ***Flexible workforce.*** This is necessary because lean manufacturers do not maintain a pool of back up/relief workers. In the event of absence of workers, retooling or changing production needs, workers must be able to perform varying tasks.

Supply Chain Management

A **Supply Chain Network (SCN)** is a **system of organizations, people, activities, information, and resources** involved in moving a product or service from **raw material suppliers to final customers**.
Unlike a simple linear supply chain, a supply chain network has **multiple suppliers, manufacturers, distributors, and customers**, connected through **material, information, and financial flows**.

Definition

A **Supply Chain Network** is a **complex, interconnected structure** consisting of suppliers, manufacturers, warehouses, distribution centers, retailers, and customers that work together to efficiently produce and deliver goods and services.

Components of a Supply Chain Network

1. **Suppliers** – Provide raw materials and components
2. **Manufacturers** – Convert raw materials into finished goods
3. **Warehouses** – Store raw materials and finished goods
4. **Distribution Centers** – Break bulk and distribute products
5. **Retailers** – Sell products to end customers

6. **Customers** – Final users of the product

Types of Flows in Supply Chain Network

1. **Material Flow** – Movement of raw materials and products
2. **Information Flow** – Demand data, forecasts, order status
3. **Financial Flow** – Payments, credit terms, invoices

Basic Supply Chain Network Diagram (Hand-Drawn Style)

SUPPLIERS
|
▼
MANUFACTURER
|
▼
WAREHOUSE
|
▼
DISTRIBUTION
CENTER
|

▼

RETAILER

|

▼

CUSTOMER

☞ *Linear representation (simplified view)*

Supply Chain Network (Multiple Nodes – Exam Diagram)

Supplier 1   Supplier 2

| |

└──────────┬──────────────┘

▼

MANUFACTURER

/   \

▼   ▼

Warehouse 1   Warehouse 2

| |

▼   ▼

Distributor 1   Distributor 2

☞ *Network structure showing multiple paths*

Objectives of Supply Chain Network Design

- Minimize **total supply chain cost**
- Improve **customer service level**
- Reduce **lead time**
- Optimize **inventory levels**
- Improve **flexibility and responsiveness**

Supply Chain Network Design Decisions

8.1 Strategic Decisions

- Number and location of facilities
- Capacity of plants and warehouses
- Supplier selection

8.2 Tactical Decisions

- Transportation modes
- Inventory policies
- Distribution planning

8.3 Operational Decisions

- Order processing
- Scheduling
- Dispatching

Factors Affecting Supply Chain Network Design

- Demand uncertainty
- Transportation cost
- Service level requirements

- Infrastructure and location
- Government policies
- Risk and sustainability

Push and Pull in Supply Chain Network

Push–Pull Boundary Diagram
SUPPLIER → MANUFACTURER → WAREHOUSE || RETAILER → CUSTOMER
(PUSH) || (PULL)

☞ *Push based on forecast, Pull based on actual demand*

Advantages of an Efficient Supply Chain Network

- Reduced operational cost
- Faster delivery
- Improved coordination
- Better demand fulfillment
- Competitive advantage

Challenges in Supply Chain Networks

- Demand variability
- Bullwhip effect
- Coordination among multiple players
- Risk and disruptions
- Information sharing issues

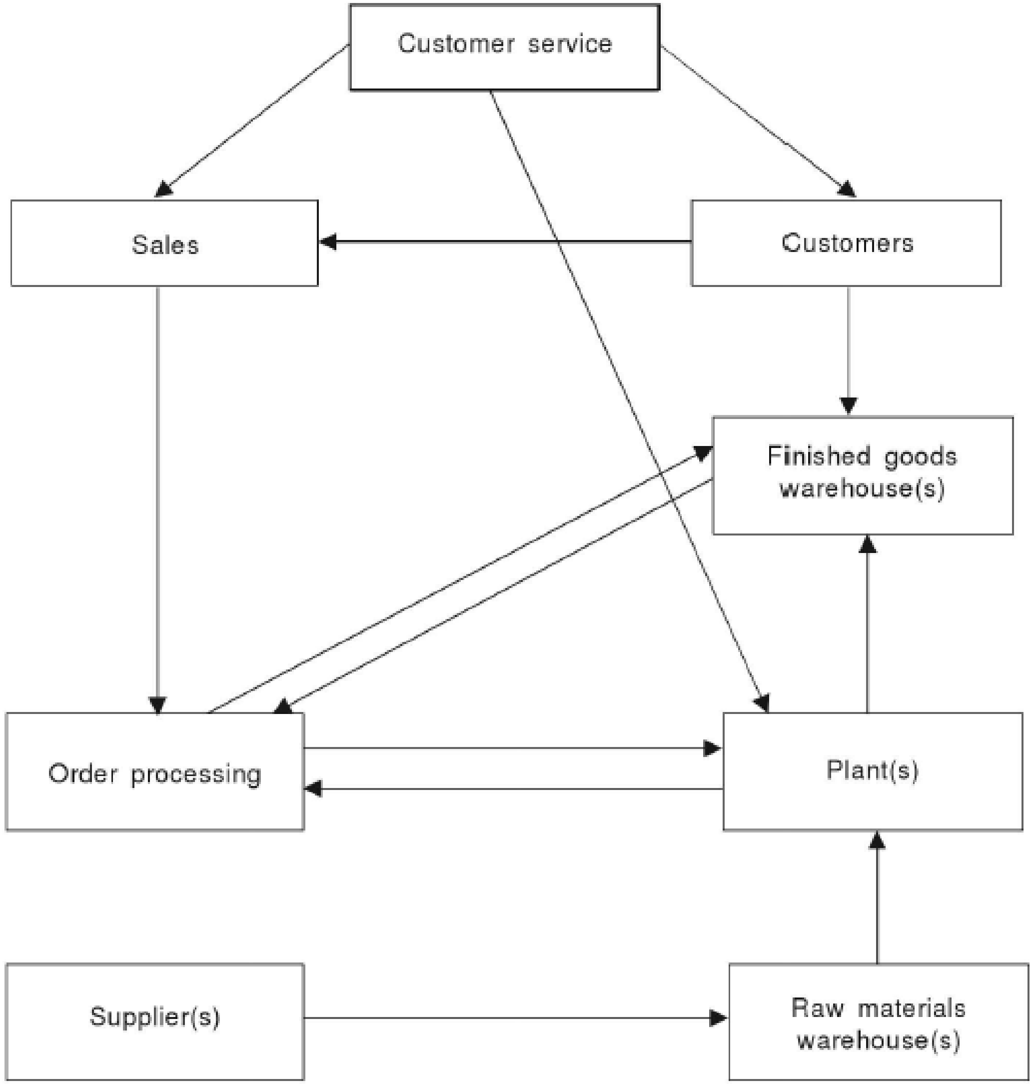
Example: Supply Chain Network of FMCG Product

Raw material suppliers → Manufacturer → Regional warehouses → Distributors → Retailers → Consumers

Benefits:

- Reduced stock-outs
- Faster replenishment
- Lower transportation cost

A supply chain network plays a crucial role in ensuring the **smooth flow of goods, information, and finances** across organizations. Effective design and management of supply chain networks lead to **cost efficiency, customer satisfaction, and long-term sustainability**.



Supply Chain Network