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Module 1. Introduction

1.1 Scope

Operations as the Core

1. Core Role of Operations

- ✓ In a business, **Operations** is like the **engine** of a car, driving the core activities of the organization.

2. Management Role

- ✓ Operations Management (OM) manages the **systems and processes** at the core of the organization.

Operations Management (OM)

Definition	OM involves managing systems/processes to create goods or provide services .
Activities	Includes acquiring inputs , processing them, and converting them into consumable products/services for end customers.
Scope	Covers both tangible products (e.g., goods) and intangible services (e.g., painting a house).
Joint Occurrence	Goods and services often occur together (e.g., paint as a good and painting as a service).

The Twin Objectives of Operations Management

1. Customer Service

The primary goal of operations management is to ensure customer satisfaction by meeting their wants and needs.

Key Focus Areas

- **Specification:** Delivering products/services that match customer requirements.
- **Cost:** Offering products/services at the right price.
- **Timing:** Providing products/services at the right time.

Significance

These three aspects (**specification, cost, timing**) are the core dimensions of customer service and contribute directly to customer satisfaction.

2. Resource Utilisation

Efficiently utilizing resources (land, labor, capital, and information) to optimize outputs and meet customer needs.

Objective

1. Customer Service Objective

Provide **adequate customer service** by delivering goods or services with the **right specifications**, at the **right cost**, and at the **right time**.

2. Resource Utilization Objective

Achieve adequate **resource utilization** (or **productivity**) by ensuring proper use of **materials, machines, and labour**.

Resource Utilization

Objective of Resource Utilization

The aim is to use resources effectively to satisfy customer needs while achieving efficient operations.

Impact of Inefficient Resources

Inefficient use of resources or poor customer service leads to commercial failure.

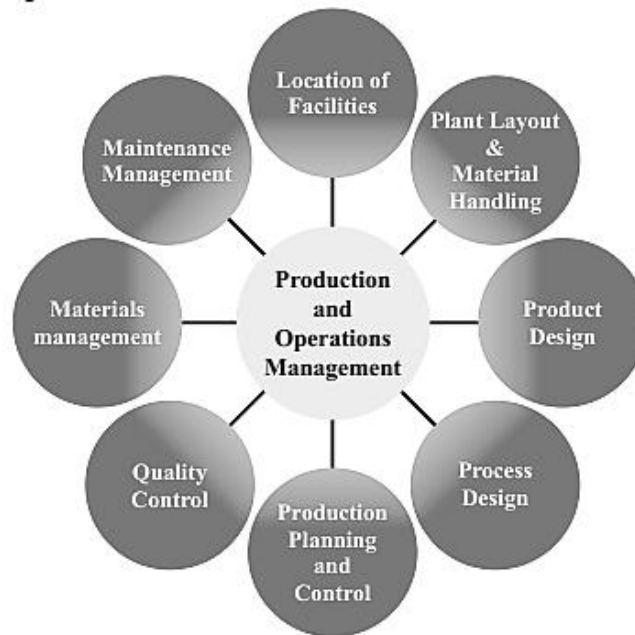
Four Principal Functions of Operations Management

Principal Function	Primary Consideration	Other Considerations
Manufacture	Goods of a specific, requested, or acceptable quality.	<ul style="list-style-type: none"> ➤ Cost: Price of the goods or cost of obtaining them. ➤ Timing: Delivery delay from order/request to receipt of goods.
Transport	Movement of goods of a specific, requested, or acceptable quality.	<ul style="list-style-type: none"> ➤ Cost: Expense of transportation. ➤ Timing: <ol style="list-style-type: none"> 1. Duration or time taken to transport. 2. Wait or delay from request to transport start.
Supply	Goods of a specific, requested, or acceptable quality.	<ul style="list-style-type: none"> ➤ Cost: Price of goods or cost of obtaining them. ➤ Timing: Delivery delay from order/request to supply.
Service	Treatment of a specific, requested, or acceptable quality.	<ul style="list-style-type: none"> ➤ Cost: Expense of the treatment or service. ➤ Timing: <ol style="list-style-type: none"> 1. Duration or time required for the treatment. 2. Wait or delay from request to start.

Scope of Operation Management

Scope of Operations Management	Operations management focuses on converting inputs into outputs using physical resources to meet customer needs and achieve organizational goals like effectiveness, efficiency, and adaptability.
Distinction from Other Functions	Unlike functions like personnel, marketing, or finance, operations management centers on conversion using physical resources.
Key Activities in Operations Management	<ol style="list-style-type: none"> 1. Location of facilities 2. Plant layouts and material handling 3. Product design 4. Process design 5. Production planning and control 6. Quality control

- 7. Materials management
- 8. Maintenance management



Scope of Production and Operations Management

1.2 Characteristics of Modern Operations Functions

Characteristic		
Manufacturing Competitive Advantage	as	In the past, production was seen as just a function. Today, companies use production to gain a competitive edge . Techniques like TQM, JIT, FMS, and CIM help companies stay ahead.
Services Orientation		With the growing importance of the service sector , production systems must meet the needs of services, such as intangibility, perishability, and local market demands . Professionals are more involved than before.
Disappearance of Smokestacks	of	Modern factories are aesthetically designed, environmentally friendly, and have transformed into knowledge-based organizations . Going to work has become a more pleasant experience.
Small has Become Beautiful		Inspired by E.F. Schumacher , the idea of small businesses and local production is gaining importance. It focuses on intermediate technology and community ownership over mass production and giant organizations.

1.3 Recent Trends in Production and Operations Management

Distinction Between Production Management and Operations Management

Production Management vs Operations Management

Production management and operations management differ in two main ways. First, **production management** refers to managing systems that create tangible products, like goods. In contrast, **operations management** focuses on processes that transform inputs into intangible services, such as those provided by banks, airlines, utilities, schools, libraries, and consulting firms, along with manufacturing businesses.

Second, the difference lies in their history. The term **operations management** is more commonly used today, while **production management** was used earlier as the field developed.

Recent Trends in Production and Operations Management
Global Marketplace Businesses are operating in multiple countries for economic benefits, increasing global competition.
Production/Operations Strategy Aligning production or operations strategies with overall business goals for better success.
Total Quality Management (TQM) Focusing on improving product and service quality to enhance customer satisfaction.
Flexibility Quickly adapting to changes in demand, product design, or delivery schedules for competitiveness.
Time Reduction Shortening production cycles and speeding up new product launches to gain an edge.
Technology Using advancements like automation and communication tools to boost operations and quality.
Worker Involvement Encouraging employee participation in decision-making through quality circles and teamwork.
Re-engineering Redesigning processes from scratch to achieve major performance improvements.
Environmental Issues Emphasizing pollution control, waste management, recycling, and eco-friendly materials.
Corporate Downsizing Streamlining the workforce to improve productivity and profitability.
Supply-Chain Management Managing the entire supply chain efficiently to reduce transportation, storage, and distribution costs.
Lean Production Producing high-quality goods efficiently with minimal resources by combining mass production and customization.

Mnemonics

Great People Take Fast Technology With Real Environmental Changes Supporting Leanness

Module 2 Operations Planning

2.1 Demand Forecasting

Forecasting

Forecasting is the process of predicting future events or needs based on available information.

- **Examples:** Predicting product demand, weather, fashion trends, tourist numbers, patient admissions, or technological advancements.

A forecast is an estimate of a future value, such as demand. Demand forecasts are essential for decision-making in operations management.

The main goal of operations management is to align supply with demand. Therefore, demand forecasting helps determine how much supply or capacity will be needed to meet future demand.

In this segment we shall restrict our discussions mainly on forecasting of demand of products.

Source of Information (used for forecasting)

To forecast demand, past information and evidence can be gathered from various sources, including:

- Market reports
- Opinions from the sales team
- Expert advice
- Industry reports
- Point-of-sales data
- Structured customer surveys
- Field reports

Range of period

Forecasting can be done for short, medium, or long-term periods, depending on the purpose. The time frame selected is based on the forecast's objective. For example:

- **Short-term forecasts:** Used for immediate needs like production planning. They typically cover 1-2 weeks or a few months.
- **Medium-term forecasts:** Cover periods from **few months to some years**
- **Long-term forecasts:** **Generally 5 to 7 years.** some cases it may extend to **10 to 15 years or more** and are used for decisions like replacing equipment or long-term planning.

The objective of each type of forecast varies.

- **Short-term forecasts** focus on accuracy and are particularly important for production planning, where managers aim to keep predictions as precise as possible.
- Short run forecasting usually spanning few months to some years

In case of short-term forecast, following purposes are generally served:

- To estimate the inventory requirement
- To provide transport facilities for dispatch of finished goods
- To decide workloads for men and machines
- To find the working capital needed
- To set-up of production run for the products
- To fix sales quota
- To find the required overtime to meet the delivery promises.

Medium run forecasting (usually for consumer durable products, medicines, period may extend over to one or two years)

The purpose of this type of forecasting is:

- To determine budgetary control over expenses
- To determine dividend policy
- To find and control maintenance expenses
- To determine schedule of operations
- To plan for capacity adjustments

Long run forecasting (usually for daily used routine household product like Aata, the normal period used is generally 5 years, in some cases it may extends to 10 to 15 years also.)

The purpose of long range forecast is:

- To work out expected capital expenditure for future developments or to acquire new facilities,
- To determine expected cash flow from sales
- To plan for future manpower requirements
- To plan for material requirement
- To plan for Research and Development. Here much importance is given to long range growth factor.

Qualitative Forecasting Methods

Method	Concept	Example
1. Survey of Buyer's Intention	Directly surveys actual users about future buying plans. Best for short-term forecasts.	A car manufacturer surveys customers about upgrading to a new model in the next six months.
2. Collective Opinion	Gathers input from salespeople, managers, and others close to customers. Consolidated to estimate sales.	A beverage company asks its sales team to estimate regional sales, then consolidates for a total forecast.
3. Group Executive Judgment	Combines opinions of top executives from various departments to create a comprehensive forecast.	A tech company's executives from marketing, finance, and production forecast demand for a new software product.
4. Expert's Opinion	Consults industry experts or external specialists to gain insights into market trends and demand.	A fashion retailer consults experts to forecast demand for an upcoming winter collection.
5. Market Test	Tests the product in a limited market, then extrapolates results to forecast total demand.	A food company launches a snack in select cities, using the data to forecast nationwide demand.

Mnemonics for Essay

To help remember the key points of the qualitative methods of demand forecasting, you can use the following Mnemonics:

"SCEGM" (pronounced "Sce-gem")

- **S:** Survey of Buyer's Intention
- **C:** Collective Opinion
- **E:** Expert's Opinion

- **G:** Group Executive Judgment
- **M:** Market Test

There are two types of approaches such as

- **Qualitative**
 - Experts Opinion Method (Delphi method)
- **Quantitative**
 - Causal/Regression analysis
 - ◆ A regression equation Y on X is of the form of $y = a + bx$
 - ◆ A regression equation X on Y is of the form of $x = (y-a)/b$.
 - ◆ The regression equations are derived through method of least square.
 - ◆ After solving by the method of least square, we get two Normal equations.
 - ◆ The two Normal equations are
 - ◆ $\sum y = na + b\sum x$
 - ◆ $\sum xy = a\sum x + b\sum x^2$

Direct and Indirect Method

- ◆ Indirect method is used for Non time series data
 - ◆ $\sum y = na + b\sum x$
 - ◆ $\sum xy = a\sum x + b \sum x^2$

- ◆ Direct Method are used for time series data

$$a = \frac{\sum y}{n}$$

$$b = \frac{\sum xy}{\sum x^2}$$

Another Easy Way

$$b = \frac{n\sum xy - \sum x * \sum y}{n\sum x^2 - (\sum x)^2}$$

$$a = \bar{y} - b\bar{X}$$

- a = y axis intercept of the regression line
- b = slope of the regression line
- X = the independent variable
- Y = the forecast value of dependent variable
- \bar{Y}, \bar{X} are mean of respective variables
- n = no of data items in X and Y series

Quantitative Forecasting - Time Series Analysis

In this method, forecasts are made using historical data of actual demand over time. The data is collected at regular intervals, such as hourly, daily, weekly, or monthly.

The demand data (Y) changes over time, and these changes are caused by four factors:

- Trend (T): Long-term movement in demand
- Seasonality (S): Regular fluctuations based on the time of year
- Cyclical (C): Fluctuations that happen over longer periods, like economic cycles
- Irregular (I) or Random (R): Unpredictable changes

These factors can be combined in two ways:

- Additive Model: $Y = T + S + C + I$
- Multiplicative Model: $Y = T * S * C * I$

Methods of forecasting by forming Trend equation

Trend (T)

The trend refers to the long-term upward or downward movement in data, often influenced by seasonal variations over time.

- The trend can be **linear or non-linear**, but linear trends are more common.
- A linear trend is represented by the equation: $F_t = a + bt$, where:
 - F_t = Forecast for a specific period t
 - a = Value of F_t when $t = 0$ (y-axis intercept)
 - b = Slope of the trend line
 - t = Number of time periods from $t = 0$

Methods of forecasting by averaging

Forecasting Methods

1. Simple Moving Average Method

- This method calculates the average of actual demand over a specified number of time periods (n).
- Formula:

$$F_t = MA_n = \frac{\sum_{i=1}^n A_{t-i}}{n}$$

Where:

- F_t : Forecast for period t
- MA_n : n -period moving average
- A_{t-i} : Actual demand in period $t-i$
- n : Number of time periods (data points)

2. Weighted Moving Average Method

- This method assigns different weights to the data points, giving more importance to recent periods.
- Formula:

$$F_t = WMA_n = \sum_{i=1}^n W_{t-i} * A_{t-i}$$

Where:

- F_t : Forecast for period t
- WMA_n : n -period weighted moving average
- A_{t-i} : Actual demand in period $t-i$
- W_{t-i} : Weight assigned to period $t-i$
- n : Number of time periods (data points)

Components of Time Series Data

1. Seasonality (S)

- Refers to short-term, regular variations in data that occur due to seasonal patterns.

2. Cycles (C)

- Describes wave-like changes in data that last more than a year, often caused by economic cycles.

3. Irregular (I)

- Represents random, unpredictable variations in the data that cannot be explained.

Definition of Seasonality (S)

Regular, predictable variations in data occurring at specific times, like holidays or rush hours.

Examples

Uber bookings during rush hour, shopping demand during festivals like Christmas.

Additive Model

Seasonality is added to or subtracted from the average to adjust for seasonal changes.

Multiplicative Model

Seasonality is expressed as a percentage of the average or trend and is multiplied to adjust.

Preference

The multiplicative model is more commonly used in businesses.

Seasonal Relative (Index)

Measures how demand in a season deviates from the average or trend.

Example of Seasonal Relative

If the index for Christmas is 1.60 and monthly sales average is 300, expected sales = $300 * 1.6 = 480$ units.

Using Seasonal Relatives

- To Deseasonalize: Divide the forecast by the seasonal relative.
- To Seasonalize: Multiply the forecast by the seasonal relative.

Methods to Find Seasonal Relatives

- Simple Average
- Centered Moving Average

2.2 Capacity Planning

Definition of Capacity

Capacity is the rate of output from an operating system per unit of time.

Capacity is based on the output that the system can produce, store, and transport.

Measurement of Capacity

Expressed as volume of output per time unit (e.g., per hour, day, or week).

Production Capacity

The maximum rate at which a facility or firm can produce goods or services.

Types of Capacity

Designed Capacity or rated Capacity

- Designed capacity is also the maximum capacity, which a facility can achieve.
- It defines the highest normal output that a process could achieve.
- Designed capacity is usually higher than the normal output.

Planned Capacity or Effective Capacity

- Planned capacity is usually less than the designed capacity.

Demonstrated Capacity or Actual Capacity

- This is the actual shown capacity.

Utilization and Efficiency

- Utilization measures how much of the design capacity is being used.

$$\text{Utilization} = \frac{\text{Actual Output}}{\text{Design Capacity}} \times 100\%$$

- A high utilization rate shows effective use of capacity and can indicate the need to add or reduce capacity.
- Efficiency measures how effectively the available effective capacity is being used.

$$\text{Efficiency} = \frac{\text{Actual Output}}{\text{Effective Capacity}} \times 100\%$$

Capacity Planning

Capacity planning answers three key questions:

1. What kind of capacity is needed?
2. How much capacity is needed?
3. When is this capacity needed?
 - Capacity planning involves long-term strategic decisions that define a firm's overall resource levels.
 - The goal is to align the firm's long-term supply capabilities with the expected demand.

Miscellaneous:

Factors Influencing Capacity Expansion

- Competitive Pressure: Need to stay ahead of competitors.
- Market Opportunities: Responding to growth or new opportunities.
- Costs and Funds Availability: Balancing costs and funding options.
- Disruption of Operations: Avoiding disruptions during expansion.
- Training Requirements: Ensuring the workforce is prepared.

Reasons for Capacity Planning

- To meet customer demand on time.
- To improve cost efficiency.
- To optimize scheduling systems.
- Capacity creation requires significant investment.
- Post-capacity planning, decisions about facility location and process technology are made.

Types of Capacity Planning

- Long-term Plans: Focus on new facilities and equipment, covering more than two years.
- Short-term Plans: Focus on workforce size, overtime, and inventory management.

Capacity Planning Activities

- Assessing current facility capacity.
- Forecasting long-term capacity needs.
- Identifying and analyzing capacity sources for the future.
- Evaluating alternatives based on financial, technological, and economic factors.
- Selecting the best capacity option to achieve the firm's strategic goals.

Possible Capacity Situations

- Excess Capacity: Current capacity exceeds future demand.
- Capacity Shortage: Current capacity is insufficient to meet forecasted demand.

Focus of Capacity Planning

- Addressing both excess and shortage capacity situations effectively.

The over capacity is preferred when:

The fixed cost of the capacity is relatively low.

- Subcontracting is not an option due to design secrecy and quality standards.
- Increasing capacity takes a long time.
- Missing delivery deadlines or losing customers is not an option for the company.
- There is a minimum capacity size below which operating the plant is not cost-effective.

Excess capacity can:

- Drain company resources
- Prevent investments in more profitable ventures.

The under capacity is preferred when:

The fixed cost of capacity is very high.

- A shortage of products does not impact the company since lost sales can be recovered.
- Technology changes quickly, making equipment and plants become outdated fast.
- Creating additional capacity is extremely expensive.

Inadequate capacity can lead to:

- Loss of customers
- Slowed growth

2.3 Facility Location and Layout

Operations Management: Key Questions

1. What to produce?
2. How much to produce?
3. Where to produce?

The question of "Where to produce?" leads to the topic of **Facility Location and Layout**.

Definition of Facility and Facility Location:

- **Facility:** Any setup an organization needs to operate, produce products, or deliver services.
- **Location:** The place or region where the facility is established.

Facility Location Decisions:

- **Key Question:** Where should the setup be established?

Need for an Appropriate Facility Location:

- When starting a new business, entering a new market, or expanding operations.
- When facing challenges like resource shortages, lease expirations, socio-cultural, legal, political, or economic issues that require relocating.

Benefits of a Good Facility Location:

1. **Cost Savings:** Lower fixed, variable, and transportation costs.
2. **Proximity:** Closer to markets and resources.
3. **Efficient Transport:** Easy and hassle-free transportation.

Summary:

A good facility location balances **costs** (production and service) and **service quality**, ensuring competitiveness by:

- Reducing costs.
- Maximizing service quality.
- Maintaining visibility and proximity to markets and resources.

It is a **strategic decision** essential for organizational success.

Factors Influencing Location Selection Decision

Factor	Description	Example
Sourcing	Availability of raw materials, natural resources, energy, water, proximity to suppliers, and connectivity to vendors. Also includes logistics factors.	A car manufacturer near steel suppliers to reduce transport costs.
Markets	Proximity to target customers , covering a wide geographical area , and ensuring quick delivery to customers.	An e-commerce company setting up near a major urban area for fast deliveries.
Cost	Includes transportation, lease/rental costs, taxes, and hidden costs .	A tech startup selecting a city with lower rental costs to reduce overhead.
Socio-cultural & Political	Community support, cultural familiarity, crime rates, employee quality of life, and compliance with regulations .	A multinational corporation in a city with high living standards to attract talent.
Environmental Concerns	Focus on air/water quality, waste disposal, and sustainability goals in choosing a location.	A renewable energy company near abundant sunlight or wind resources .
Skilled Labor	Availability of skilled workers near educational institutions or regions with high talent concentrations.	A software company near a city known for tech talent and proximity to top universities.
Competitive Pressure	Presence of competitors and choosing locations with a competitive advantage, like access to key resources or markets.	A retail chain opening in a location with few competitors for larger market share.
Operational Efficiency	Availability of growth space, better transportation, reduced plant operational costs, and a cordial labour situation .	A manufacturing plant with space to expand and cost-effective operations .
Sustainability	Focus on environmental impact such as water, air, and land quality, as well as compliance with sustainability goals .	A company in an area with better environmental conditions .
Technological Connectivity	Internet access, digital infrastructure, and overall technological readiness of a location.	A tech company choosing a location with fast internet and high-tech infrastructure .
Strategic Benefits	Logistics improvement, centralized control, better inter-plant coordination, and the potential for increased future profitability .	A company selecting a site to improve supply chain coordination and future growth .

Mnemonics to remember "SMART COSTS"

- **S:** Sourcing (Availability of raw materials, natural resources, energy, water, proximity to suppliers, connectivity to vendors, cross-docking opportunities)
- **M:** Markets (Proximity to market, wide geographical coverage, connectivity with a large customer base, lesser time to market)
- **A:** Availability of skilled labor
- **R:** Regulatory and socio-cultural issues (Supportive community, familiarity with language and culture, crime levels, availability of employees, quality of living, statutory regulations, medical facilities)
- **T:** Transportation and cost (Lesser transportation cost, availability of transportation modes, lease/rental cost, taxes, hidden costs)
- **C:** Competitive pressure
- **O:** Operational efficiency (Growth space, better transportation network, reduced plant operations and service costs, cordial labor situation)
- **S:** Sustainability and environmental concerns (Better environment in terms of water, air, and land)
- **T:** Technological connectivity (Availability of internet connectivity)
- **S:** Strategic benefits (Improved logistics, inter-plant coordination, centralized control, increased future plant profitability)

Popular Methods for Facility Location Selection

Factor Rating Method

Evaluate locations based on weighted factors.

Center of Gravity Technique

Find a central location to minimize transportation costs.

Transportation Model

Optimize costs and distribution.

Optimization and Heuristic Models

Use mathematical models to find the best location.

Facility Layout

Definition

Organizing departments, work areas, and equipment for smooth material and workflow.

Scope

Includes planning locations for machines, tools, storage areas, offices, restrooms, etc.

Types of Layout:

Process Layout

➤ Also called **functional layout** or **job shop layout**. Machines are grouped based on similar processes.

Product Layout

➤ Also called **line processing layout** or **flow-line layout**. Machines are arranged in the sequence of production.

Fixed Position Layout

- Also called **static layout**. The product remains stationary, and materials and workers are brought to it.

Cellular Manufacturing (CM)

- Also called **Group Technology layout**. Machines are grouped into cells to handle similar products or processes.

Combination Layout

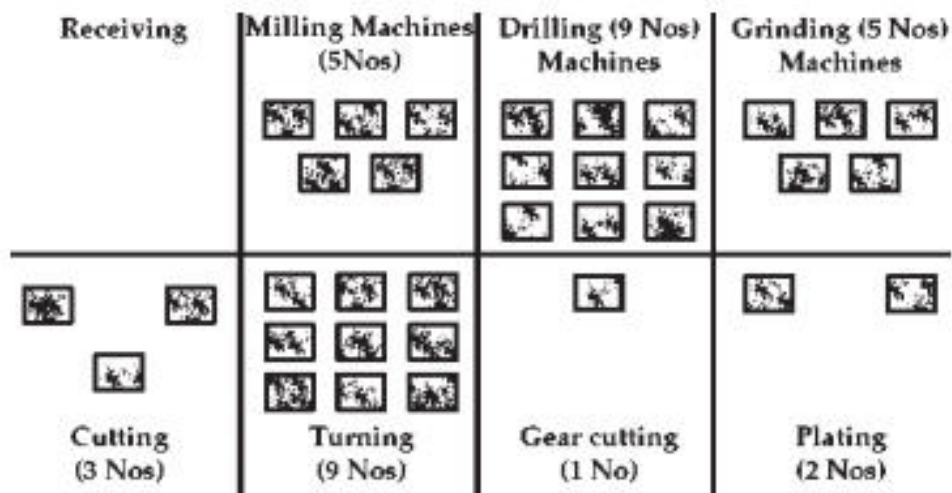
- Also called **Hybrid layout**. A mix of different layout types to optimize production.

Process Layout:

The **Process Layout** (also called **functional layout**, **job lot manufacture**, or **batch production layout**) groups similar machines in one department based on their function. For example:

- **Drilling machines** are placed in the **drilling department**.
- **Turning machines** are placed in the **turning department**.
- **Milling machines** are placed in the **milling department**.

This layout is based on the idea of grouping machines with similar operations together.



Process Layout

Suitability

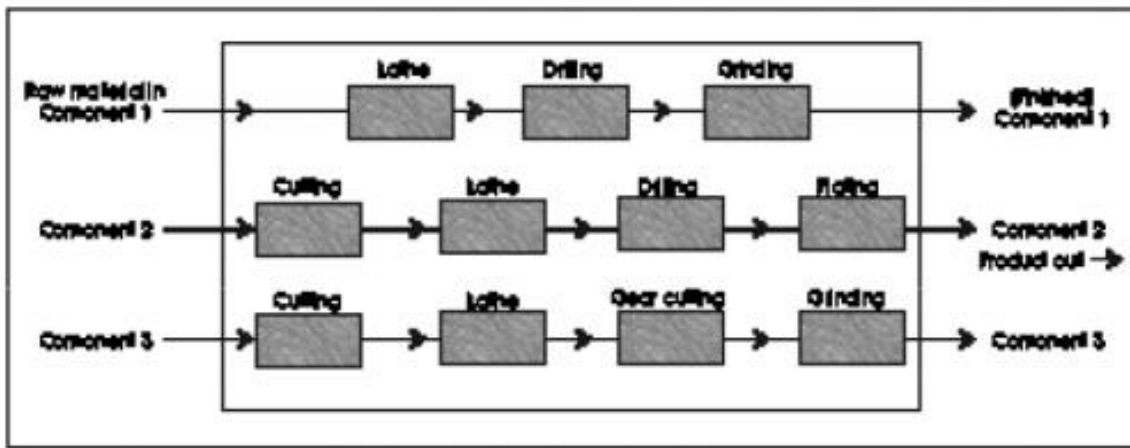
- This layout is best for **intermittent production**.

Product Layout:

The **Product Layout** (also called **straight-line layout** or **serialised manufacture**) arranges machines in a straight line according to the sequence of operations.

- Materials are fed into the first machine, and the finished product comes out of the last machine, with partly finished goods moving from one machine to the next.
- For example, in a **sugar mill**, **sugar cane** is processed into **sugar**, and in a **paper mill**, **bamboo** is processed into **paper**.

In this layout, if there are multiple production lines, each line has its own set of machines. The focus is on using **special purpose machines**, unlike the **general purpose machines** used in the **process layout**. This results in higher **investment** in machines compared to the functional layout.



Product Layout

Suitability

- Product layout is best for plants manufacturing standardized products on a mass scale, such as in industries like chemical, paper, sugar, rubber, refineries, and cement.

Layout in the form of Fixed Position:

Layout Type

Fixed Position Layout

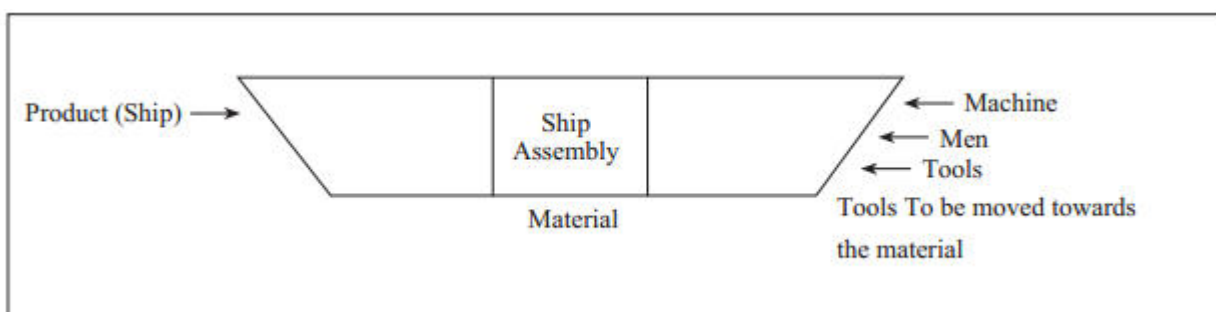
- Also called static layout. The product stays stationary, and machines, tools, and workers are brought to it.

Cost Efficiency

- Moving men and machines to the product is more cost-effective than moving the bulky product itself.

Suitability

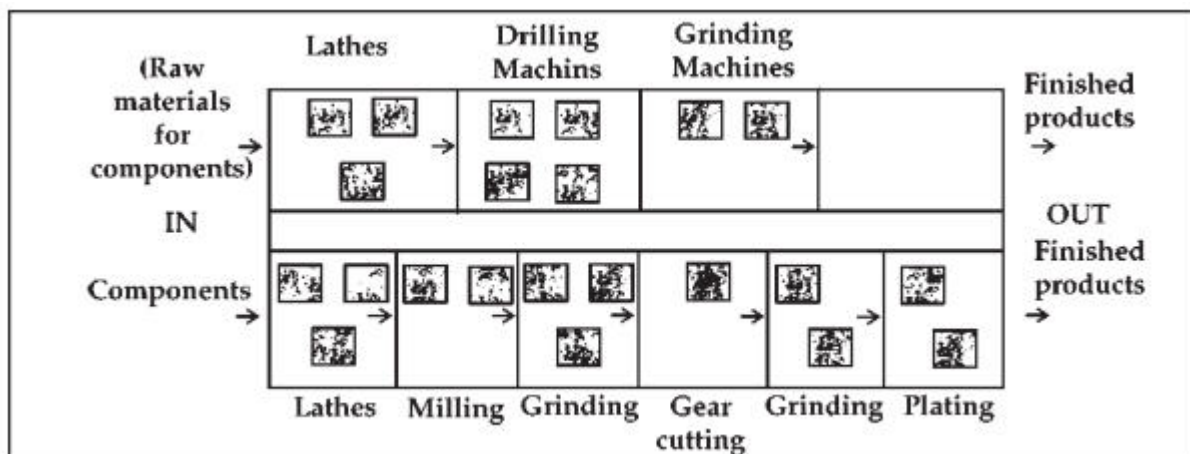
- Used for manufacturing bulky and heavy products like locomotives, ships, boilers, aircraft, and generators.



Fixed Position Layout

Mixed Layout or Combined Layout

The application of product layout and process layout in their pure forms is rare. Most industries use a combination layout, with an emphasis on one or the other. This combined layout is efficient when the products being manufactured are similar and not complex.



Component flow in combined layout

Layout of Service Facility:

Facility Type
Service Facility Layout <ul style="list-style-type: none"> ➤ Focuses on bringing customers and services together. ➤ Should provide easy entrance from freeways and busy thoroughfares. ➤ Requires large parking areas, well-organized walkways, and ample lighting.
Types of Service Facility Layouts <ul style="list-style-type: none"> ➤ Customer-focused layouts: Designed around customer service, like banks. ➤ Technology-focused layouts: Designed around processing and production efficiency, like hospitals.

2.4 Resource Aggregate Planning

Aggregate Planning	<ul style="list-style-type: none"> ➤ Intermediate-range production planning (3 months to 2 year). ➤ Plans quantity and timing of output, considering aggregate demand (e.g., thousands of liters of paint or number of cars).
Fluctuating Demand (Challenge)	➤ When demand fluctuates, the company has several alternatives:
Alternatives for Fluctuating Demand	<ol style="list-style-type: none"> 1. Level production: Produce at a constant rate and use inventory to absorb demand fluctuations. 2. Chase demand: Hire and fire workers to match changing demand. 3. Maintain resources for high demand periods. 4. Vary working hours (e.g., overtime or under time). 5. Subcontracting work to other firms. 6. Use part-time workers to adjust capacity. 7. Backordering: Provide the service/product at a later time.
Strategy Type	<ul style="list-style-type: none"> ➤ Pure Strategy: A company uses only one of the above methods. ➤ Mixed Strategy: A company combines two or more of the above methods.

Strategies for Aggregate Planning (To be made ,for alternative for fluctuating demand)

Strategy	Description	Example
Vary the Size of the Workforce	Adjust the workforce size based on demand. Hire additional workers when demand is high and reduce staff when demand decreases to avoid excessive labor costs.	A retail company hiring seasonal workers during the holiday season and reducing staff afterward.
Vary the Hours Worked	Maintain a stable workforce, but adjust the number of hours worked. Employees may work overtime during peak demand or have idle time during low demand.	A manufacturing plant using overtime during peak production periods to meet demand without hiring more staff.
Vary Inventory Levels	Adjust inventory levels by building up stock during low demand and using it to meet higher demand later. Requires careful management to avoid excess stock.	An electronics manufacturer producing extra units during off-peak seasons for the holiday season.
Subcontracting	Outsource production to external vendors when demand rises. Helps meet demand without expanding internal capacity.	A clothing brand subcontracting to a third-party manufacturer during a surge in demand for a new line.

Conclusion :

Aggregate planning balances demand and capacity over the intermediate term. Strategies like adjusting workforce size, varying hours, managing inventory, and subcontracting allow companies to meet fluctuating demand while minimizing costs.

2.5 Material Requirements Planning

Material Requirement Planning (MRP)

Material Requirement Planning (MRP) is a vital technique used in manufacturing to determine the quantity and timing for acquiring dependent demand items needed to satisfy master production schedule requirements

MRP Objectives

- Inventory reduction
- Reduction in manufacturing and delivery lead times
- Realistic delivery commitments
- Increased efficiency

Mnemonic for MRP Objectives

To remember the key objectives of MRP, you can use the mnemonic "IRRI":

- I: Inventory reduction
- R: Reduction in lead times
- R: Realistic delivery commitments
- I: Increased efficiency

2.6 Manufacturing Resource Planning

Concept	
MRP II Overview	<ul style="list-style-type: none"> ➤ Manufacturing Resource Planning (MRP II) helps managers plan and control the manufacturing process and related support functions. ➤ Covers areas like materials, capacity, finance, engineering, sales/marketing. ➤ Universally applicable to any manufacturing organization, regardless of size, location, product, or process.
MRP II as a Management Process	<ul style="list-style-type: none"> ➤ Breaks down the business plan into detailed tasks. ➤ Involves all departments: materials, engineering, sales/marketing, purchasing, and manufacturing. ➤ Departments must meet deadlines for both bought-out and in-house manufactured items.
MRP I vs MRP II	<ul style="list-style-type: none"> ➤ MRP II is an evolution of MRP I. ➤ MRP I focuses on materials and CRP focuses on time. ➤ MRP II integrates material, time, and other functions like finance, personnel, and engineering. ➤ MRP II is the heart of the corporate management information system for many manufacturers.

2.7 Economic Batch Quantity

Concept	
Economic Lot Size	<ul style="list-style-type: none"> ➤ The optimum lot size or Economic Lot Size (ELS) is the most economical batch size to produce, minimizing the average production cost. ➤ It helps determine the quantity of output produced in one batch to meet anticipated demand. ➤ Economic Order Quantity (EOQ) is often used interchangeably with Economic Batch Quantity (EBQ) or Economic Manufacturing Quantity (EMQ).
Factors Affecting Economic Lot Size	<ol style="list-style-type: none"> 1. Usage Rate: The rate of production should match the rate of usage of parts in assembly. 2. Manufacturing Cost: Larger lot sizes reduce per unit cost due to distributed setup costs, but increase carrying costs (handling, storage). 3. Deterioration & Obsolescence: Larger lot sizes increase the risk of loss due to deterioration (shelf life) or obsolescence (technology/product design changes).
Capacity Verification	<ul style="list-style-type: none"> ➤ Before choosing an economic lot size, ensure production capacity is available to produce the required batch size.
Balancing Costs	<ul style="list-style-type: none"> ➤ The economic lot size balances two opposing costs: <ol style="list-style-type: none"> 1. Setup Costs: Decreases with larger lot sizes. 2. Inventory Carrying Costs: Increases with larger lot sizes.
Key Concept	<ul style="list-style-type: none"> ➤ A larger lot size results in lower setup costs per unit but higher inventory carrying costs.

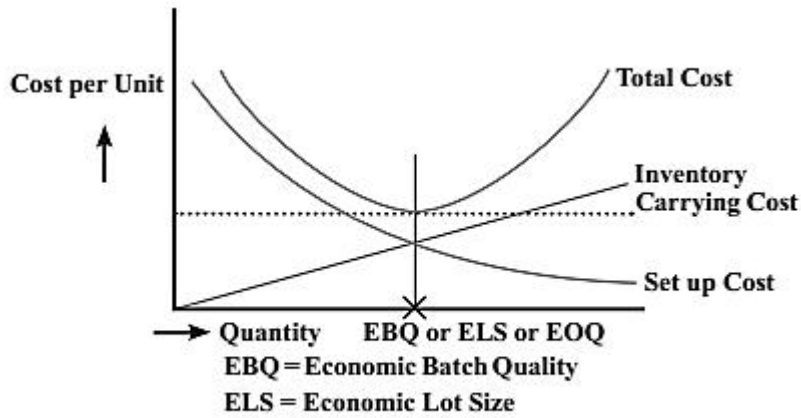


Figure 2.6: Economic Lot Size

Economic Batch Quantity (EBQ):

Formula:

$$EBQ \text{ (or EOQ, ELS, EMQ)} = \sqrt{\frac{2AS}{C}}$$

$$= \sqrt{\frac{2 \times (\text{Annual demand in unit}) \times (\text{Setup cost per setup})}{[\text{Production Cost per unit}] \times [\text{Inventory carrying charges (\%)}]}}$$

- S** = Setup cost per setup (Ordering Cost)
- A** = Annual demand (units)
- C** = Production cost per unit
- I** = Inventory carrying (holding) charges (%)

Economic Run Length (ERL):

ERL is used when a company produces an item for inventory instead of buying it.

Formula:

$$ERL = \sqrt{\frac{2AS}{C1(1-\frac{d}{p})}}$$

$$= \sqrt{\frac{2 \times [\text{Annual demand (in unit)}] \times (\text{Setup cost per setup})}{[\text{Production Cost per unit}] \times [\text{Inventory carrying charges (\%)}] (1 - \frac{\text{Demand Rate}}{\text{Production Rate}})}}$$

- S** = Setup cost per setup
- A** = Annual demand (units)
- C1** = Production cost per unit
- d** = Demand rate (consumption rate)
- p** = Production rate
- (1 - p)** adjusts for the difference between production rate and demand rate.

Module 3. Designing of Operational System and Control

3.1 Product Design

Product Design	Product design involves a structured process to develop value propositions that meet customer needs and add value, impacting the overall value chain.
Objectives of Product Design	<ol style="list-style-type: none"> 1. Meet customer needs and provide optimum value. 2. Minimize cost and lead time (design to market). 3. Maximize resource utilization.
Importance of Product Design	<ol style="list-style-type: none"> 1. Establish characteristics (core and augmented) based on market demand and competition. 2. Provide technical requirements for defining processes. 3. Guide production system design. 4. Support production and operations strategy.
Impact of Good Product Design	Helps organizations stay ahead of competition, build long-term customer relationships, and drive employment growth.
Attributes of Good Design	<ol style="list-style-type: none"> 1. User-friendliness 2. Features 3. Aesthetics 4. Reliability 5. Durability 6. Innovativeness 7. Appropriateness.
Responsibilities of Product Design	<ol style="list-style-type: none"> 1. Translate customer requirements (Voice of the Customer) into technical requirements (Voice of the Process). 2. Differentiate existing products to extend product life cycle. 3. Develop new products. 4. Formulate quality goals. 5. Cost optimization. 6. Build and test prototypes. 7. Document design specifications.

Factors affecting the Product Design

Understanding Customer Needs	1. Stated and unstated needs : Discovering latent needs is challenging, often done through social media analytics .
User-Friendliness	2. Products should attract diverse demographics by being easy to use.
Balance Between Form, Function, and Cost	3. Achieve the right balance between economies of scale and economies of scope .
Quality of Raw Materials	4. Ensure high-quality raw materials or basic ingredients for the product.

Process and Layout Design	5. Select and design the processes and layouts for efficient production.
Machine/Instrument Quality	6. Machines and instruments used in the design process should be of high quality and maintained well.
Process Capability and Maturity	7. Ensure process maturity and capability for smooth execution.
Skilled Resources	8. The design process must have skilled professionals to ensure quality.
Impact on Existing Products	9. Consider the effect on existing products when introducing new designs.
Product Presentation	10. Pay attention to packaging and presentation of the product to make it appealing.

Characteristics of Good Product Design

Product Quality	1. Satisfy customer needs and deliver optimum value. Performance should meet customer expectations .
Reliability	2. The product should be reliable and worthy of the price paid.
Cost Optimization	3. Designed at an optimum cost to be offered at an affordable price for the target market.
Design-to-Market Lead Time	4. Product must have a shorter design-to-market lead time to stay competitive.
Aesthetics	5. The looks of the product should create an immediate impression on customers.
Compatibility and Support	6. The product must be user-friendly, compatible, and upgradable with after-sales support (e.g., spare parts).
Maintainability and Reproducibility	7. Product should be easily maintainable and reproducible .
Balance Between Features	8. Maintain a balance between standardized basic features and customized augmented features .
Specification	9. Provide a detailed specification for the product.
Safety and Environmental Impact	10. Ensure the product is safe to use, error-proof, and environmentally friendly .

3.2 Process Design and Selection

Product Characteristics	Nature and type of product
Variety	Level of customization and standardization : <ul style="list-style-type: none"> ➤ Make to Order ➤ Make to Stock ➤ Engineer to Order ➤ Assemble to Order
Volume	Quantity to be produced, e.g.: <ul style="list-style-type: none"> ➤ Single piece ➤ Batch production

	<ul style="list-style-type: none"> ➤ Continuous production
Human Resource Involvement	Process automation based on labor involvement: <ul style="list-style-type: none"> ➤ Automatic (least manual labor, capital-intensive) ➤ Semi-automatic ➤ Manual (labor-intensive)
Resource Requirements	Includes: <ul style="list-style-type: none"> ➤ Machines (special-purpose/general) ➤ Human capital ➤ Space ➤ Energy ➤ Raw materials and others
Expenditure	Operational costs: <ul style="list-style-type: none"> ➤ Fixed costs ➤ Overhead costs
In-house or Outsourcing	Decision between: <ul style="list-style-type: none"> ➤ In-house ('Make') production ➤ Outsource ('Buy') production

These major process decisions are discussed in detail in the following paragraphs:

Process Type	Characteristics	Examples
Job Shop Process	<ul style="list-style-type: none"> ➤ Low volume, high-variety goods. ➤ Intermittent processing. ➤ High customization (made to order). ➤ Requires flexible equipment and skilled labor. ➤ Uses a flexible flow strategy, resources organized around processes. 	Tool and die shops, custom tool manufacturing.
Batch Process	<ul style="list-style-type: none"> ➤ Moderate volume and moderate variety. ➤ Products/services are repeatedly provided. ➤ Volume higher than job shops, but lower than repetitive processes. 	Paint, ice cream, soft drinks, books, magazines.
Repetitive Process	<ul style="list-style-type: none"> ➤ High volume, standardized goods/services. ➤ Slightly flexible equipment, low labor skills. ➤ Resources organized around the product/service. ➤ Line flow with fixed sequence and minimal work-in-progress inventory. ➤ Suited for manufacture-to-stock or assemble-to-order strategies. 	Automobiles, home appliances, toys, computers, televisions.

Continuous Process	<ul style="list-style-type: none"> ➤ Very high volume, highly standardized products. ➤ No variety, no equipment flexibility. ➤ Capital intensive, operates round-the-clock to maximize utilization. 	Petroleum, steel, sugar, paper, cement, fertilizers.
Project Process	<ul style="list-style-type: none"> ➤ High degree of customization. ➤ Large scope and substantial resources required. ➤ Involves complex activities, often long durations. ➤ Equipment flexibility and labor skills vary by project. 	Building dams, bridges, shopping centers, new product development, book publishing.

3.3 Product Life Cycle

Stage	Characteristics	Key Highlights
Introduction Phase	<ul style="list-style-type: none"> ➤ Product is introduced in the market (new product or variant). ➤ Low volume, low sales, and low ROI. ➤ High promotional expenditure. ➤ Pricing depends on product innovativeness and target customers. Discounts are often given to attract buyers. 	<ul style="list-style-type: none"> ➤ First market entry ➤ Learning curve effect not realized. ➤ High promotional campaigns.
Growth Phase	<ul style="list-style-type: none"> ➤ Focus on revenue generation and market expansion. ➤ Sales cover fixed costs, reduce overhead costs, and benefit from previous learning. ➤ Promotional strategies target both existing and new customers. 	<ul style="list-style-type: none"> ➤ Rapid market growth. ➤ Target cost efficiency and increase customer base.
Maturity Phase	<ul style="list-style-type: none"> ➤ Market reaches saturation. ➤ Goal shifts to slowing down decline. ➤ Introduce product variety and differentiation to find niche markets or restart a new PLC. ➤ Use aggressive promotional and pricing strategies. ➤ Profit margins are lower. 	<ul style="list-style-type: none"> ➤ Critical phase for maintaining market position. ➤ Focus on flattening the curve. ➤ Engage in differentiation.
Decline Phase	<ul style="list-style-type: none"> ➤ Product loses market attractiveness. ➤ Falling sales and narrowing profit margins. ➤ Decisions include scrapping the product or focusing on cost consolidation. ➤ Sometimes, revival through product differentiation and promotional strategies is attempted. 	<ul style="list-style-type: none"> ➤ Transition to decline. ➤ Consider revival plans or discontinuation.

A typical PLC for a FMCG product and high tech product are given in following figures

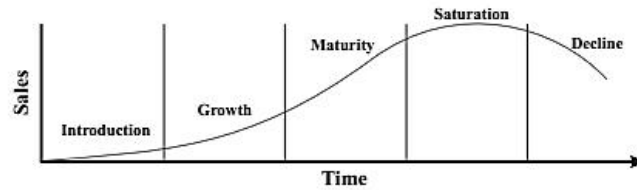


Figure 3.2: PLC for FMCG Product

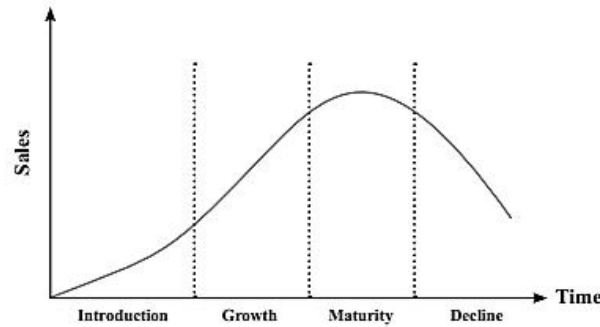


Figure 3.3: PLC for High Tech Product

3.4 Process Planning and Selection

Definition

Involves decisions on **facility selection, layout planning, work system design, operating procedures, capacity planning,** and arrangement of resources.

Process Strategy

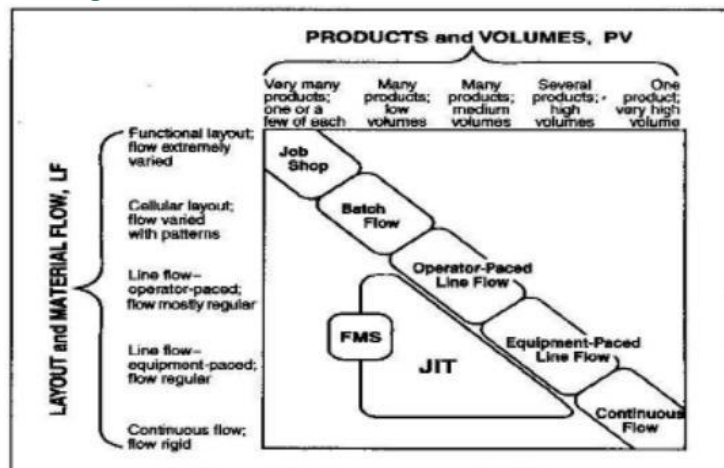
Definition	Decision on selecting processes to convert inputs (resources) into outputs (products/services) as per product specifications.
Key Factors	<ul style="list-style-type: none"> ➤ Long-term efficiency and productivity. ➤ Resource availability. ➤ Flexibility. ➤ Cost and benefits. ➤ Quality. ➤ Lead time.
Premises	<ul style="list-style-type: none"> ➤ Make vs Buy: Fully/partially in-house or outsourced production. ➤ Capital intensity: Balance between automation and manual operations. ➤ Process flexibility.
Facility Focus Areas	
Process-Focused	<ul style="list-style-type: none"> ➤ Facility designed around processes. ➤ Equipment and workstations are flexible for frequent changes. ➤ Suited for customization (Job shop production). <p>Example: Aircraft production.</p>
Product-Focused	<ul style="list-style-type: none"> ➤ Facility designed around products. ➤ Suited for high volume, low variety production. ➤ Achieves economies of scale and learning benefits. <p>Examples: Steel, glass, paper, electric bulbs, chemicals, pharmaceutical products.</p>

Repetitive Focus	<ul style="list-style-type: none"> ➤ Combines benefits of process- and product-focused strategies. ➤ Uses modular production (Assembly production). <p>Examples: Automobiles, household appliances.</p>
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Process Layout Selection

Process Objectives	<ul style="list-style-type: none"> ➤ Efficient production. ➤ Minimizing movements and transportation. ➤ Efficient material handling. ➤ Workstation optimization. ➤ Removing bottlenecks. ➤ Space utilization.
Goal	Deliver value-added products to customers while minimizing waste , optimizing operational costs , and maximizing resource utilization .
Types of Layouts	
Process Layout (Functional)	<ul style="list-style-type: none"> ➤ Groups similar machines/services together. ➤ Best for low volume, high variety production (e.g., job shops, batch production). <p>Examples: Furniture, restaurants.</p>
Product Layout (Line)	<ul style="list-style-type: none"> ➤ Organized based on sequential flow of activities. ➤ Suitable for high volume, low customization. <p>Examples: Assembly lines in electronics, automobiles.</p>
Group (Combination) Layout	<ul style="list-style-type: none"> ➤ Combines features of process and product layouts. ➤ Uses cellular manufacturing, reducing transportation and material handling costs.
Fixed Position (Project) Layout	<ul style="list-style-type: none"> ➤ Facilities remain fixed, while materials and resources move to the site. ➤ Used for highly customized, single-use products. <p>Examples: Aircraft, ships.</p>
Production System Considerations	
Suitability	Each production system is optimized for a specific mix and volume of products and delivers varying levels of cost, quality, delivery, and flexibility .
PV-LF Matrix Dimensions	<ul style="list-style-type: none"> ➤ Number of products produced. ➤ Production volume of each product. ➤ Layout of equipment and processes. ➤ Material flow through processes.

A typical PV-LF diagram is given below



3.5 Design Thinking

Definition

A **non-linear, iterative process** focused on understanding **users' needs**, challenging assumptions, redefining problems, and creating **innovative solutions** through **prototyping and testing**.

Purpose

Best suited for tackling **ill-defined or unknown problems**.

Phases

Five stages described by the Hasso Plattner Institute of Design at Stanford (**d.school**). These stages are iterative and can be repeated or conducted in parallel.

Stage	Objective	Key Highlights
1. Empathize	<ul style="list-style-type: none"> ➤ Gain an empathetic understanding of the problem through user research. ➤ Set aside assumptions and gain real insights into users' needs. 	<ul style="list-style-type: none"> ➤ Human-centered approach. ➤ Crucial for understanding users.
2. Define	<ul style="list-style-type: none"> ➤ Accumulate and analyze observations from the Empathize phase. ➤ Synthesize information to create problem statements. ➤ Use personas to keep efforts human-centered. 	<ul style="list-style-type: none"> ➤ Core focus on defining users' needs and problems.
3. Ideate	<ul style="list-style-type: none"> ➤ Generate innovative ideas by challenging assumptions. ➤ Use brainstorming and explore alternative solutions to the problem statement. 	<ul style="list-style-type: none"> ➤ Encourages creative thinking and outside-the-box solutions.
4. Prototype	<ul style="list-style-type: none"> ➤ Create scaled-down versions of the product or features. ➤ Test ideas through experimentation. 	<ul style="list-style-type: none"> ➤ Experimental phase. - Focus on identifying the best solutions.
5. Test	<ul style="list-style-type: none"> ➤ Conduct rigorous testing of prototypes. ➤ Use results to refine solutions, identify further problems, or revisit earlier phases for improvements. 	<ul style="list-style-type: none"> ➤ Iterative process for refining solutions.

Module 4. Application of Operation Research - Production Planning and Control

4.1 Introduction

Applications of Operations Research

Operations Research (OR) is used differently across various fields. Depending on the specific needs, the right OR method is chosen to solve problems and get results. Below are some common examples of how OR is applied.

National Planning and Budgeting

- **Five-Year Plans** preparation.
- Creating **annual budgets**.
- **Forecasting** income and expenditure.
- **Scheduling** major national projects.
- Estimating **GNP, GDP, population, and employment**.
- Predicting **agricultural yields** and **energy generation**.

Defence Service Operations

- Developing **new technology**.
- Optimizing **cost** and **time** in defence projects.
- **Tender evaluation** for technology and equipment.
- Deciding the **location and layout** of defence factories.
- Conducting **threat analysis** of enemy forces.
- Planning effective **battle strategies** and **tactics**.
- Ensuring efficient **maintenance and replacement** of equipment.
- Planning **defence supplies** strategies during war and peace.
- Evaluating vendors for **canteen stores**.
- Managing **inventory control**.
- Addressing **transportation problems** during mobilization and operations.
- Conducting **mock simulation exercises**.
- Identifying ideal **supply depot locations** to support operational units.

Industrial Field

- Plant location and siting.
- Finance planning.
- Product and process planning.
- Facility planning and factory building layout.
- Purchasing, vendor evaluation, and bid evaluation.
- Inventory control.
- Maintenance management and replacement.
- Personnel management, such as merit rating and incentive payments.

R&D and Engineering

- Technology forecasting.
- Technology evaluation.
- Technology management.

- Project management for turnkey projects.
- Systems evaluation.
- Tender preparation.
- Negotiation.
- Value engineering and component selection.
- Work study, method study, and activity sampling.

Business Management and Competition

- Making business decisions under risk and uncertainty.
- Capital investment and returns.
- Selection of business and areas of operations.
- Decision-making under competition.
- Business strategy formation.
- Optimal advertisement spending.
- Optimal sales force and their distribution.
- Market survey and analysis.
- Using market research techniques.

Agriculture and Irrigation

- Project management of irrigation projects and dams.
- Construction of major dams at minimum cost.
- Optimum distribution of irrigation canals.
- Optimum location of input supply points (seeds, fertilizers) for farmers.
- Optimum location of agricultural collection points.

Education and Training

- Optimum number and location of schools.
- Optimum student/teacher ratio.
- Optimum financial outlay to meet national education objectives.
- Optimum number and location of examination centers and student distribution.
- Location of educational supply depots.
- Demand and supply of textbooks and stationery.

Public Works Department

- Time and cost control for roads, bridges, and buildings.
- Project completion time estimate.
- Time estimates for various project activities.
- Selection of machines and equipment.
- Maintenance and replacement of infrastructure.
- Preparation of budgets for public works.
- Tender evaluation and bid selection.

Transportation and Communication

- Forecast public transport needs.
- Optimum routing of buses for maximum utility.
- Estimate/forecast income and expenses for transport services.
- Project management for railway projects within time and cost limits.
- Railway network distribution.

- Forecast telephone demand.
- Optimum capacity selection for telephone exchanges.
- Optimum number of busy-hour calls for exchanges.

Home Management and Budgeting

- Control expenses to maximize savings.
- Optimum number of provisions to purchase.
- Order quantity of provisions for each purchase.
- Time management for household tasks.
- Work-study and time-study for kitchen activities.
- Preparation of budgets for categories like provisions, petrol, vegetables, meat, etc.
- Invest surplus income for maximum profit.
- Selection of investments to minimize taxes and maximize returns.
- Appropriate life and property insurance.
- Estimate depreciation and optimum insurance premium.

Operations Research (OR) Techniques

There are various techniques used in OR. Some of these are listed here:

- Probability theory
- Statistical methods
- Frequency distribution
- Graphical solution LP
- Linear programming simplex
- Transportation algorithm
- Assignment of problem
- Game theory
- Decision-tree approach.
- Replacement theory
- Simulation model
- PERT/CPM method
- Break-even analysis (BE)
- Forced decision matrix method
- Discounted Cash Flow (DCF) and Net Present Value (NPV) method
- Trend analysis and time series
- Correlation techniques
- Variance analysis
- Significance analysis
- Statistical quality Control (SQC) techniques
- Dynamic programming, etc.

Application-Specific Techniques:

- The effectiveness of OR techniques depends on the specific problem being solved.
- Selecting the right technique is crucial for maximum benefit.
- Each technique has its own advantages and limitations, and managerial skills are tested in choosing the right one.

Sl. No.	Functional Area	Specific Problem	OR Techniques Applicable
1	Production Management	Siting and location	Location dynamics BE, Routing travel charts
		Factory layout, Product planning	Profitability analysis, Product line analysis
		Process planning	Line of balance (LOB), Routing GT
		Technology selection	Forced decision matrix - bid evaluation
		Facility planning	Capital investment, Selection of plant, BE, DCF
		Workstation design	Line balancing, Heuristic Methods
		Capacity planning	Break-even, Decision tree, Statistical
		Selection of plant Product mix	BE mathematical, DCF/NPV, LP simplex, LP graphical
		Production planning & control	BE Sequencing assignment, Scheduling
2	Materials Management	Warehouse/stores Layout, Inventory Control, Vendor rating	Transportation algorithm, EOQ, ABC & VED analysis Functional analysis, Forced decision matrix
		Value engineering, Make or buy decision	Break-even, Decision tree, DCF
3	R&D and Engineering	Technology selection, System analysis reliability	Forced decision matrix, Statistical probability, Statistical frequency distribution
4	Quality Management	Inwards goods inspection	Statistical, probability, AQL, OC curve
		Outwards goods inspection	Statistical, probability, AQL
		Process inspection	Statistical, Frequency distribution, CSP
5	Servicing Industry	Optimum efficiency	Queuing theory
		Saving of waiting time	Monte-Carlo simulation
6	Maintenance Management	Maximisation of utilization and minimization of cost	Replacement theory, Statistical DCF, MAPI
7	Project Management	Time estimate	Statistics, Frequency distribution
		Minimisation of time	PERT
		Minimisation of cost	CPM/CPM
8	Marketing Management	Forecast demand	Trend analysis, Probability, Statistics
		Marketing strategy	Game theory, Markov's chain simulation
9	Finance Management	Capital investment costing	DCF, NPV, ROI, PI, Ratio analysis, Variance analysis, Signification, Decision tree

Scope of Operations Research

The scope of Operational Research (OR) is not limited to specific fields like defense or industry. Instead, it has a broad range of applications. OR is valuable in any area where resources need to be optimized. It's easier to list areas where OR isn't used than where it is. Some key fields where OR plays a significant role include:

This list is by no means exhaustive, but only illustrative.

- National plans and budgets.
- Defence services and battle field operations.
- Government development and public sector units.
- Industrial establishments and private sector units.
- R&D and engineering divisions.
- Business management and marketing.
- Agriculture and irrigation projects.
- Education and training.
- Public works department and construction of mega projects.
- Transportation and communication.
- Home management and personal budgeting, etc.

4.2 Production Planning and Control

Definition	Production planning and control acts as the nervous system of production, ensuring timely delivery of products to customers or inventory.
Primary Objective	To plan, coordinate, organize, and control all activities in the production cycle to meet a predetermined schedule.
Control in Production	Ensures that labour, materials, and facilities are effectively utilized to meet the firm's objectives and handle complex production systems.

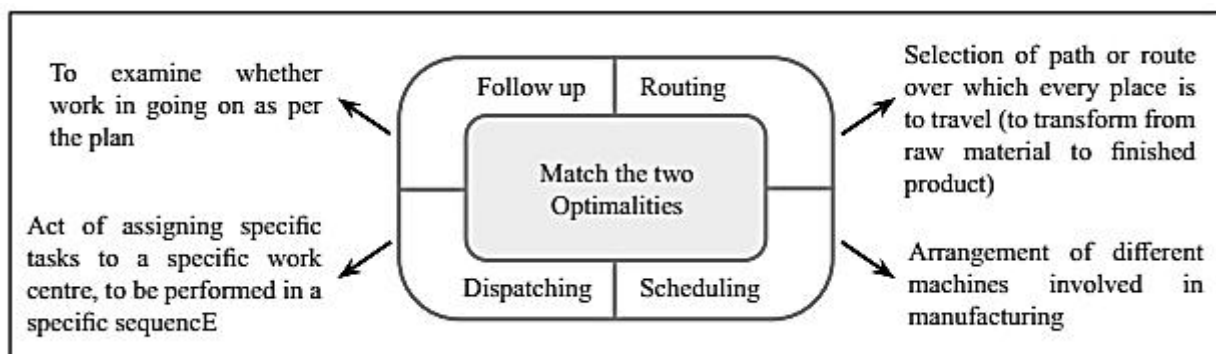
Objectives of production planning and control

Ultimate Objective	To contribute to profits by keeping customers satisfied through meeting delivery schedules.
Specific Objectives	To establish routes and schedules that ensure optimum utilization of raw materials, labour, and machines.
Focus Area	Control of work-in-process by managing the flow of materials, and the utilization of people and machines.
Key Activities	
1. Order Analysis	Determining raw materials and parts needed for order completion.
2. Customer Queries	Answering questions about the status of orders.
3. Cost Estimates	Assisting the costing department in preparing cost estimates.
4. Manpower Planning	Assisting HR in manpower planning and assigning workers to jobs.
5. Stock Control	Managing stock of finished parts and products.
6. Tools Determination	Identifying necessary tools for manufacturing.
7. Material Movement	Directing and controlling the movement of materials through the production process.

8. Order Changes	Implementing customer-requested changes while orders are in process.
9. Material Requisitions	Issuing requests for the purchase of materials.
10. Tool/Part Requisitions	Issuing requests for the purchase or manufacture of tools and parts.
11. Record Maintenance	Keeping up-to-date records of scheduled and in-process activities.
12. Material/Part Stocks	Maintaining stocks of materials and parts.
13. Production Feasibility	Notifying sales and accounting about order acceptance in terms of production feasibility.
14. Route Sheets and Schedules	Preparing route sheets and schedules showing the sequence of operations for products.
15. Work Orders	Issuing work orders to initiate production activities.
16. Progress Reports	Receiving and evaluating progress reports on orders and initiating corrective actions if necessary.
17. Order Reception	Receiving orders from customers.
18. Revising Plans	Revising plans when production cannot conform to original schedules or when rush orders require adjustments.

Production control involves the following functions:

1. Planning	Detailed planning of production operations.
2. Routing	Defining the path for work and the order of operations to be performed.
3. Scheduling	Establishing the quantity of work and setting a time table for operations.
4. Dispatching	Issuing necessary orders and ensuring that time targets in the schedule are met.
5. Follow-up	Checking if work progresses as per predetermined plans and identifying variances from set standards.
6. Inspection	Conducting occasional quality checks of manufactured or assembled products to maintain high standards.



Techniques of Production Control

Basic types of production control:

Type of Production Control	
1. Block Control	Common in textiles and book/magazine printing, where items must be kept separated to maintain order.
2. Flow Control	Used in continuous production systems like chemicals, petroleum, and glass. Controls the rate of flow into and out of the system. Routing and scheduling are set when the plant layout is designed.
3. Load Control	Applied where a bottleneck machine exists in the production process.
4. Order Control	Common in intermittent production systems (job-lot shops). Plans and controls are based on individual orders with varying quantities and products.
5. Special Project Control	Used in construction projects (e.g., bridges, hospitals). Relies on close supervision by individuals or teams instead of elaborate tools or forms.
6. Batch Control	Found in batch production systems, especially in food processing. Operates with specific controls for each batch of production.

4.3 Control Measures - Time & Motion Study, Method Study, Work Study

Time Study:

Concept	
Time Study	A scientific analysis of methods and equipment to find the best way to do a job and determine the time required.
Job Analysis	Determines essential factors of a job and the worker qualifications needed for its performance.
Time vs. Motion Study	The main aim of motion study is to eliminate wastefulness resulting from ill-directed and inefficient motions.. Time study determines the best method using equipment and sets standards for production, costs, and wages.

Work Study:

Concept	
Work Study	A general term for techniques like methods study and work measurement used to examine and improve human work.
Objective	To find the best and most efficient way to use resources: men, materials, money, and machinery.
Methods Study	Develops an improved procedure for performing tasks.

Method Study:

Definition	Systematic investigation of existing methods to develop an easy, efficient, and cost-effective procedure for a job.
Objective	Achieved by eliminating unnecessary motions, changing the sequence of operations, or altering the process itself.

4.4 Optimum Allocation of Resources - LPP

Definition	Linear Programming is an optimization technique for determining how to use limited resources to achieve objectives like least cost, highest margin, or least time.
Applicability	Useful for finding the best values of variables under constraints,
Key Parts of Linear Programming	
1. Objective Function	Describes the primary goal: to maximize return (e.g., profit) or minimize cost (e.g., production or investment cost).
2. Constraint Set	A system of equalities and/or inequalities representing the restrictions or conditions for optimization.

Definition of Linear Programming

Kohlar	LP involves constructing a model of a real situation with: (a) Variables representing choices, (b) Mathematical expressions: (i) Relating variables to controlling conditions, (ii) Reflecting criteria to measure benefits of different plans, (iii) Establishing the objective to ensure selection of the best alternative.
Samuelson, Dorfman & Solow	LP is the analysis of problems where a linear function of variables is to be maximized or minimized under restraints in the form of linear inequalities.
Lomba	LP is part of a systems approach to management, where all programs are designed and evaluated for their impact on achieving business objectives.

Application Areas of Linear Programme

1. Industrial Applications	Linear programming is widely used to solve industrial problems by determining plans that satisfy demand without violating constraints. (a) Product Mix Problem (b) Production Scheduling (c) Production Smoothing Problem (d) Blending Problems (e) Transportation Problems (f) Production Distribution Problems (g) Trim Loss Problems (h) Oil refineries: Optimizing the mix of products to be produced in a given period. (i) Communication Industry: Optimizing transmission, switching, and relaying facilities. (j) Railroad Industry: Scheduling freight and train movements at large terminal switching rail points.
2. Management Applications	(a) Portfolio Selection (b) Financial Mix Strategy (c) Profit Planning (d) Media Selection

	(e) Travelling Salesman Problem (f) Equitable Salary Determination (g) Staffing Problem
3. Miscellaneous Applications	(a) Farm Planning: Crop selection, acreage allocation, and production methods. (b) Airline Routing (c) Administration, Education, and Politics: Solving various problems. (d) Diet Problems: Determining the most economical diet for patients (e.g., hospitals).
4. Administrative Applications	Optimizing resources like men, machines, and materials in administration.
5. Non-Industrial Applications	(a) Agriculture (b) Environmental Protection (c) Urban Development (d) Facility Location
6. Further Applications	(a) Structural Design: Maximizing product. (b) Assembly Line Balancing (c) Military Tanker Fleet Scheduling (d) Deciding parts to make vs. buy for maximum profit. (e) Selecting equipment and methods for profit maximization. (f) Planning sales to match plant capacity for fair market share. (g) Designing optimal purchasing policies.

Definitions

Solution	Values of decision variables (x_j) that satisfy the constraints of an L.P.P.
Feasible Solution	A solution that satisfies both the constraints and the non-negativity restrictions.
Basic Solution	
Basic Feasible Solution	A feasible solution which satisfies all the constrain and non negativity restrictions.
Optimal Feasible Solution	A basic feasible solution that maximizes or minimizes the objective function.
Degenerate Solution	A basic solution where one or more basic variables become zero.

Slack Variables	Added to " \leq " constraints to convert them into equalities. Example: $2x_1 + 3x_2 \leq 500$ $2x_1 + 3x_2 + S_1 =$ Where $S_1 =$ slack variable.
Surplus Variables	Subtracted from " \geq " constraints to convert them into equalities. Example: $3x_1 + 4x_2 \geq 100$ $3x_1 + 4x_2 - S_2 = 100$ Where $S_2 =$ surplus variable.
Artificial Variables	Fictitious variables introduced to facilitate computation when constraints are in " \geq " form. Represented by A and solved using Big-M or Two-Phase Method.
Big-M Method	A modified simplex method assigning a high penalty cost to artificial variables in the objective function, applicable for minimization and maximization.

Simplex Tableau	A table showing and entering values of basic variables at each stage of iteration in simplex calculations.
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Primal and Dual Linear Programming

Concept	
Primal	The original Linear Programming Problem (LPP) .
Dual	The LPP associated with the primal. If the dual is stated as the problem, the primal becomes its dual and vice versa.
Relationship	The solution of one (primal or dual) contains the solution of the other and can be derived from the same optimum tableau .

Characteristics of Primal and Dual

Characteristic	
1. Problem Type	If the primal is a maximization problem , the dual will be a minimization problem , and vice versa.
2. RHS Constants and Objective Coefficients	Primal RHS constants become dual objective coefficients and vice versa. $C^* = b^T, b^* = C^T$.
3. Constraints Coefficients	The dual constraint coefficients are the transpose of the primal constraint coefficients, and vice versa. $A^* = A^T$.
4. Constraint Form	Primal maximization: Constraints are in \leq form. - Dual minimization: Constraints are in \geq form.

4.5 Transportation

Topic	
Origins	<ul style="list-style-type: none"> ➤ First developed by F.L. Hitchcock in 1941 (study: "Distribution of a product from several sources to numerous locations"). ➤ Further studied by T.C. Koopmans in 1947 (study: "Optimum utilization of the transportation system").
Definition	Involves transporting a product from supply origins (e.g., factories) to demand destinations (e.g., warehouses) while minimizing transportation cost .
Objective	Determine the number of units to be transported from each origin to each destination to: <ul style="list-style-type: none"> ➤ Satisfy destination demands. ➤ Stay within plant capacity constraints. ➤ Minimize the total transportation cost.
Applications	Common in supply chains involving: <ul style="list-style-type: none"> ➤ Movement from plants to warehouses. ➤ Warehouses to wholesalers. ➤ Wholesalers to retailers. ➤ Retailers to customers.

Transportation Table (Matrix)

Initial Basic Feasible Solution

Concept	
Objective	Start with a basic feasible solution and proceed step-by-step toward the optimal solution (minimum cost).
Methods Available	Various methods can be used to obtain the initial basic feasible solution .

Method	
1. North-West Corner Rule	Also known as: ➤ Upper-left corner rule
2. Minimum Cost Matrix Method	Allocations are based on the overall minimum cost in the entire matrix.
3. Vogel Approximation Method (VAM)	Also called the Unit Penalty Method , it calculates penalties to determine allocations.

North - West Corner Rule

North-West Corner Rule for Transportation Problems

Concept	
Objective	Allocate transportation quantities (x_{ij}) to minimize transportation cost while meeting supply and demand constraints.
Key Principle	Allocations are made using the " first come, first served " approach, without considering cost coefficients (c_{ij}).

Minimum Cost Matrix Method

Objective	Allocate transportation quantities (x_{ij}) by considering the smallest cost (c_{rs}) in the entire cost matrix of the transportation table.
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Step	
1. Smallest Cost in Matrix	Identify the smallest cost (c_{rs}) in the entire cost matrix of the transportation table.
2. Initial Allocation	Assign $x_{rs} = \min(a_r, b_s)$: ➤ If $a_r \leq b_s$: Set $x_{rs} = a_r$, exhausting the supply at O_r . ➤ If $b_s \leq a_r$: Set $x_{rs} = b_s$, exhausting the demand at D_s , leaving $a_r - b_s$ units available at O_r .
3. Next Smallest Cost	Identify the next smallest cost in the matrix and repeat the allocation process.
4. Repeat Until Completion	Continue the process until all sources (O_1, O_2, \dots) and destinations (D_1, D_2, \dots) are exhausted.
5. Calculate Total Cost	Compute the total transportation cost (Z) using the formula: $Z = \sum c_{ij} x_{ij}$.

Vogel Approximation or Unit Penalty Methods

Concept	
Objective	Provides a better initial basic feasible solution compared to other methods by considering penalty costs for allocations.

Recap of Previous Methods

Method	Key Principle
North-West Corner Rule	Allocations are based on a " first come, first served " approach, without considering transportation costs.
Minimum Cost Matrix Method	Allocations are based on the smallest cost in the entire matrix , without preference for rows or columns.

Key Features of Vogel Approximation Method

Feature	
Relative Minimum Costs	VAM considers the difference between the smallest and next smallest costs in each row and column.
Penalty or Loss	This difference is called the penalty cost and indicates the loss incurred if the smallest cost is not used.
Row and Column Penalties	Penalties are calculated for all rows and columns to prioritize allocations.
Selection of Allocation	The greatest penalty is chosen first to minimize future losses, even if it corresponds to a higher cost.

Complexities in transportation

Concept	
Unbalanced Problem	<ul style="list-style-type: none"> ➤ Occurs when aggregate supply \neq aggregate demand. ➤ Supply > Demand: Add a dummy destination column with requirement equal to the excess supply and transportation cost = 0. ➤ Supply < Demand: Add a dummy origin row with capacity equal to the excess demand and transportation cost = 0. ➤ Balancing ensures the problem proceeds normally.
Prohibited Routes	<ul style="list-style-type: none"> ➤ For unavailable routes, assign a very large cost (M) to the unavailable routes. ➤ Solve the problem as usual.
Degeneracy	<ul style="list-style-type: none"> ➤ Occurs when the number of occupied cells in a basic feasible solution $\neq m + n - 1$. ➤ Can happen in two ways: <ol style="list-style-type: none"> 1. Initial solution degeneracy: Occurs when initial feasible solution results in fewer cells. 2. During MODI: Happens when two or more cells are vacated simultaneously during transfers. Solution: Assign an infinitely small amount (ϵ) to an independent empty cell (one that doesn't form a closed loop). Preferably assign ϵ to the cell with the lowest per-unit cost. ✓ Treat cells with ϵ as occupied and solve as usual.

	<ul style="list-style-type: none"> ✓ Key formula: ✓ $k + \varepsilon = k, \varepsilon + \varepsilon = \varepsilon, k - \varepsilon = k, \varepsilon - \varepsilon = 0, 0 + \varepsilon = \varepsilon, k \times \varepsilon = 0.$
Maximisation Problem	<p>For problems requiring profit maximisation:</p> <ol style="list-style-type: none"> 1. Replace profit values with their differences from the highest profit value in the matrix (i.e., subtract each profit value from the maximum profit).. The new matrix is known as Opportunity loss matrix, Opportunity Cost Matrix, Relative Loss Matrix or Pay Off Matrix 2. Solve using the usual transportation method. 3. Calculate maximum profit using the original profit values for assigned cells.

4.6 Job Evaluation, Job Allocation - Assignment

Assignment

Concept	
Assignment Problem	<ul style="list-style-type: none"> ➤ The assignment problem involves assigning people, machines, or resources to tasks where each person or machine has a different cost to perform each task. ➤ The goal is to minimize the total cost of assignments.
Methods to Solve Assignment Problem	<ol style="list-style-type: none"> 1. Complete Enumeration Method 2. Simplex Method 3. Transportation Method 4. Hungarian Method (most common)
Hungarian Method	Steps involved in minimizing the assignment cost using the Hungarian Method :
Step 1: Row Operation	<ul style="list-style-type: none"> ➤ Find the smallest cost element in each row of the cost table. ➤ Subtract this smallest element from all elements in that row. ➤ This results in at least one zero in each row, creating the reduced cost table.
Step 2: Column Operation	<ul style="list-style-type: none"> ➤ In the reduced cost table, find the smallest element in each column. ➤ Subtract this smallest element from all values in the column. ➤ This creates at least one zero in each row and column, forming a second reduced cost table.
Step 3: Optimality Check	<ul style="list-style-type: none"> ➤ Draw the minimum number of horizontal and vertical lines to cover all the zero elements. ➤ If the number of lines drawn is equal to n (number of rows or columns), the solution is optimal. If not, go to Step 4.
Step 4: Improved Matrix	<ul style="list-style-type: none"> ➤ Identify the smallest uncovered cost element (not covered by any line). ➤ Subtract this element from all uncovered elements and add it to intersections of two lines. ➤ Elements covered by only one line remain unchanged.
Step 5: Repeat Steps 3 & 4	➤ Repeat Step 3 and Step 4 until the optimal solution is obtained.
Step 6: Assignment	Once optimal solution is found, make assignments based on zero elements : (a) Find rows with only one zero and assign the corresponding task.

	<p>(b) Cross out the zero in the corresponding column.</p> <p>(c) Repeat for columns with only one zero.</p> <p>(d) If no row or column has only one zero, select a row/column arbitrarily and assign a task. Alternative solutions may exist.</p>
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Job Evaluation:

Concept	
Job Evaluation	<ul style="list-style-type: none"> ➤ Job evaluation is the process of ranking, grading, and weighing job characteristics to determine the worth of jobs. ➤ It aims at fairness and consistency in wages and salaries within an organisation. ➤ The process enhances employee confidence when systematic and impartial.
Steps in Job Evaluation	<ol style="list-style-type: none"> 1. Preparation of preliminary job descriptions. 2. Analysing jobs to create final job descriptions and specifications. 3. Assessing job worth based on approved descriptions.
Job Description and Specifications	<ul style="list-style-type: none"> ➤ Job description outlines the content of a job. ➤ Job specifications are derived from job descriptions and specify the qualifications needed for the position. ➤ Job specifications guide the personnel department in selecting and placing employees.
Factors Affecting Job Value	<p>Key factors to determine job value include:</p> <ol style="list-style-type: none"> 1. Qualifications required. 2. Job difficulties. 3. Responsibilities. 4. Working conditions. <ul style="list-style-type: none"> ➤ These factors help create detailed job descriptions and affect the job's relative worth.
Systems of Job Evaluation	<p>Common systems used in job evaluation include:</p> <ol style="list-style-type: none"> 1. Ranking or grading method. 2. Factor comparison method. 3. Point rating method. <ul style="list-style-type: none"> ➤ All systems involve analyzing specific factors to determine the job's relative worth.
Ranking or Grading Method	<ul style="list-style-type: none"> ➤ Jobs are written on cards, and grading is done by competent judges. ➤ Hourly rates are suggested by the judges based on the rank of each job. ➤ The average rank score is used to fix hourly rates.
Factor Comparison Method	<ul style="list-style-type: none"> ➤ Jobs are analyzed in greater detail compared to grading method. ➤ Jobs are ranked based on factors such as mental requirements, skills, physical demands, responsibility, and working conditions. ➤ A money value is assigned to each factor's rank, and the total worth of the job is calculated by summing the values. ➤ More accurate and flexible than ranking.

Point Rating Method	<p>Three types of methods under point rating:</p> <ol style="list-style-type: none"> 1. Straight point method: Equal weights assigned to each characteristic. 2. Weighted point method: Different weights for different characteristics. 3. Direct-to-money method: Job characteristics are ranked and compared directly to monetary values. <ul style="list-style-type: none"> ➤ Used to assign points based on job characteristics to determine the job's value.
Straight Point Method	<ul style="list-style-type: none"> ➤ All job characteristics are assigned equal weights. ➤ Range of values is assumed to be between the same maximum and minimum points for each characteristic.
Weighted Point Method	<ul style="list-style-type: none"> ➤ In this method different points are assigned to the different characteristics of doing jobs.
Direct-to-Money Method	<ul style="list-style-type: none"> ➤ Select key jobs whose wage rates are believed to be correct. ➤ Job characteristics are assigned monetary values. ➤ Jobs are ranked according to the degree of characteristics and this helps to identify any errors in wage distribution.

4.7 Scheduling and Queuing Models

Concept	
Scheduling	<ul style="list-style-type: none"> ➤ Scheduling is the process of determining the start and completion timings for each operation in the production process. ➤ It aims to maximize machine and operator utilization while avoiding unnecessary burden. ➤ It involves deciding when each operation starts and the order of tasks. ➤ Key objective: To plan the time required for each operation and the overall production process.
Purpose of Scheduling	<ul style="list-style-type: none"> ➤ Ensures efficient use of time, machines, and manpower. ➤ Establishes the sequence of operations and time allocations for each task. ➤ Scheduling depends on factors such as routing, method of production, production quantity, raw material transportation, production capacity, and customer delivery dates.
Relationship between Routing and Scheduling	<ul style="list-style-type: none"> ➤ Routing and Scheduling are interconnected and interdependent processes. ➤ Routing defines the sequence of operations, while Scheduling determines the time required for each operation. ➤ Routing is a prerequisite for Scheduling because it establishes the operations, tools, equipment, and personnel involved. ➤ Scheduling informs Routing by providing the time schedules for each operation.

	<ul style="list-style-type: none"> ➤ Without scheduling, it is difficult to plan an efficient route, as it lacks timing details. ➤ Routing aims to find the most economical and efficient route, while Scheduling ensures that the resources are utilized optimally and on time.
Key Conclusion	<ul style="list-style-type: none"> ➤ Routing and Scheduling are complementary and must work together for effective production planning and control. ➤ Both processes rely on each other to ensure maximum efficiency in production.

➤ **Lean Operations Priority Rules**

Common Priority Rules	<ol style="list-style-type: none"> 1. First Come First Served (FCFS): Jobs are processed in the order of arrival. 2. Shortest Operations Time (SOT/SPT): Process jobs with the shortest completion time first. 3. Due Date (DDATE): Process jobs in the order of earliest due dates. 4. Slack Time Remaining (STR): Process jobs with the least slack time remaining. <ul style="list-style-type: none"> ➤ Formula: $STR = (Due\ Date - Today's\ Date) - Remaining\ Processing\ Time$. 5. Critical Ratio (CR): Process jobs with the least critical ratio. <ul style="list-style-type: none"> ➤ Formula: $CR = (Due\ Date - Today's\ Date) / Remaining\ Processing\ Time$. ➤ $CR > 1$: Ahead of schedule; $CR < 1$: Behind schedule; $CR = 1$: On schedule. 6. Last Come First Served (LCFS): Process the latest arriving job first. 7. Longest Processing Time (LPT): Process jobs with the longest processing time first.
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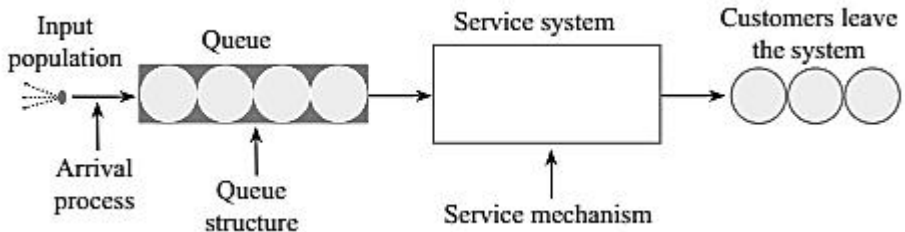
Queuing models

General Structure of Queuing System

The general structure of a queuing system is depicted in Figure 4.3

1. Source	<ul style="list-style-type: none"> ➤ Infinite Source: Large populations where removing one customer has no noticeable effect. ➤ Finite Source: Small populations where removing one customer significantly affects the remaining demand. 	<p>Example: Shoppers at a superbazar (city/state level population).</p> <p>Example: Ten machines in a factory needing maintenance.</p>
2. Numbers	<ul style="list-style-type: none"> ➤ Individual Arrivals: Customers arrive one at a time. ➤ Batch Arrivals: Customers arrive in groups or bulk. 	<p>Example: Visitors to a beautician, students at a library counter.</p> <p>Example: Families visiting a restaurant, ships discharging cargo at a dock.</p>

3. Arrival Timing	<ul style="list-style-type: none"> ➤ Deterministic Models: Arrival times are known and occur at regular or predictable intervals. ➤ Stochastic Models: Arrivals occur randomly and are described using probability distributions (commonly Poisson distribution). 	<p>Example: Known scheduling of arrivals.</p> <p>Example: Random customer arrivals at a service counter.</p>
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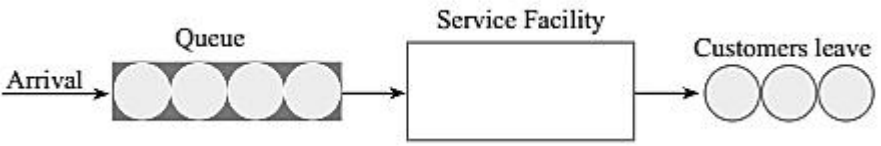
General Structure of the Queuing System

1. Arrival process:
2. Service system:

(a) Structure of the Service System

1. Single Service Facility:

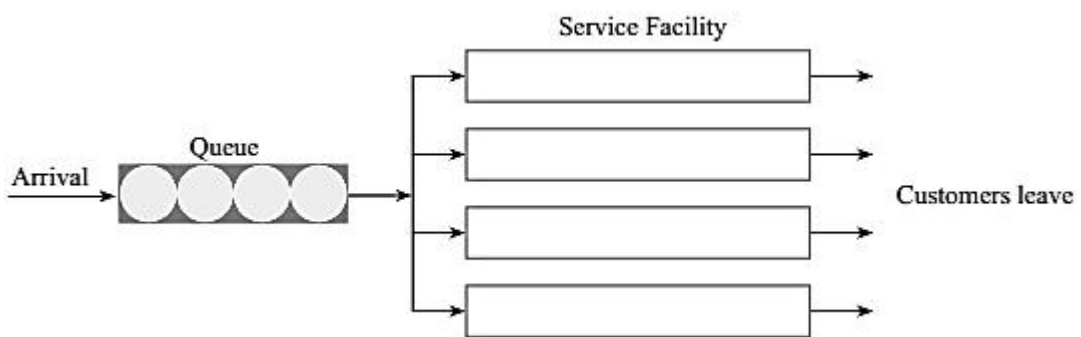
- ✓ One server provides service sequentially.
- ✓ Example: A library counter.



Single Server, Single Queue Model

2. Multiple, Parallel Facilities with Single Queue:

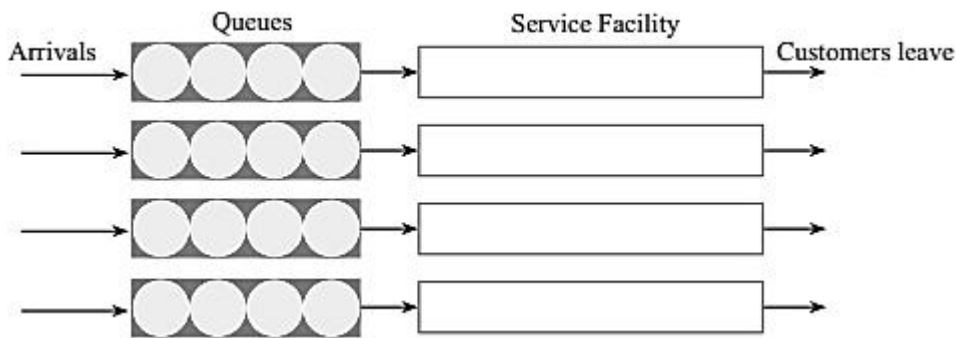
- ✓ Multiple servers share one queue and provide the same service.
- ✓ Example: Mechanics at a service station.



Multiple, Parallel Servers, Single Queue Model

3. Multiple, Parallel Facilities with Multiple Queues:

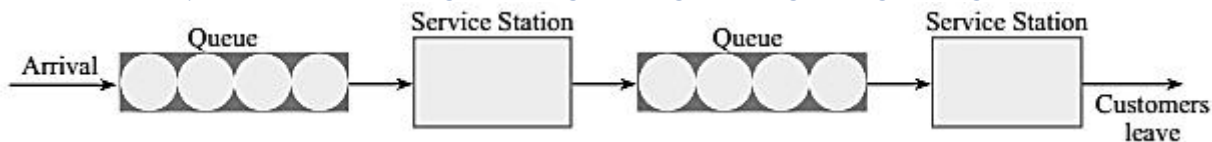
- ✓ Each server has a separate queue, and customers choose which to join.
- ✓ Example: Different cash counters in an electricity office.



Multiple, Parallel Servers, Multiple Queues Model

4. Service Facilities in Series:

- ✓ Customers receive service at multiple stations in sequence, with each handling part of the process.
- ✓ Example: Steel machining involving cutting, turning, and grinding.



Multiple Servers in Series

Operating Characteristics of Queuing System

Characteristic

1. Queue Length

Average number of customers waiting in the queue for service.

- Large queues: Poor server performance.
- Small queues: Excess server capacity.

2. System Length

Average number of customers in the entire system (both waiting and being serviced).

- Large system length: Indicates congestion and customer dissatisfaction.
- May require increased service capacity.

3. Waiting Time in Queue

Average time a customer waits in the queue before receiving service.

- Long waiting times: Cause dissatisfaction and potential loss of revenue.
- Very short waiting times: Suggest excess service capacity.

4. Total Time in System

Average time a customer spends in the system (from entering the queue to leaving after service).

- Large values: Indicate need for capacity adjustments.

5. Server Idle Time

Relative frequency with which the server is idle (not serving customers).

- High idle time: Increases cost.
- Reducing idle time may affect other characteristics negatively (e.g., longer queues).

Measures of waiting-line performance

1. Average number of customers waiting	Refers to the number of customers either in line or in the system .
2. Average waiting time	The time customers spend waiting, either in line or in the system .
3. System utilization	The percentage of capacity utilized ; measures how busy servers are compared to being idle.
4. Cost of capacity and waiting line	Refers to the costs associated with the level of capacity and the waiting line.
5. Probability of waiting	The likelihood that a customer will have to wait for service.
Elaboration on System Utilization	<ul style="list-style-type: none"> ➤ Indicates how busy servers are. ➤ 100% utilization is not ideal; leads to excessive waiting times and long lines. ➤ Slack time is necessary for service personnel. ➤ Goal: Minimize the sum of waiting costs and capacity costs.

Queuing Models: Infinite-source

Queuing Models Overview	Many models exist for managers and analysts to choose from. The focus here is on four basic and widely used models .
Assumptions of the Models	<ul style="list-style-type: none"> ➤ Poisson arrival rate. ➤ Operate under steady-state conditions: average arrival and service rates are stable.
Key Models	<ol style="list-style-type: none"> 1. Single server, exponential service time. 2. Single server, constant service time. 3. Multiple servers, exponential service time. 4. Multiple priority service, exponential service time.
Terminology	The terms " server " and " channel " are interchangeable.
Facilitation Note	Table 4.5 provides symbols used for infinite-source models .

Symbol	Represents
λ	Customer arrival rate
μ	Service rate per server
L_q	The average number of customers waiting for service
L_s	The average number of customers in the system (waiting and/or being served)
R	The average number of customers being served
ρ	The system utilization
W_q	The average time customers wait in line
W_s	The average time customer's spend in the system (waiting in line and service time)
$1/\mu$	Service time
P_0	The probability of zero units in the system
P_n	The probability of n units in the system
M	The number of servers (channels)
L_{max}	The maximum expected number waiting in line

Let λ stands for arrival as ' μ ' stands for service.

✓ Probability that service is busy

$$\text{(Not idle)} = \frac{\lambda}{\mu}$$

✓ Probability that service is idle

$$= 1 - \left(\frac{\lambda}{\mu}\right)$$

✓ Probability that 'n' unit in the system

$$= \left(\frac{\lambda}{\mu}\right)^n \left(1 - \frac{\lambda}{\mu}\right)$$

✓ Average number of units in the system

$$= \frac{\lambda}{\mu - \lambda}$$

✓ Average number of units in the queue.

$$= \frac{\lambda^2}{\mu(\mu - \lambda)}$$

✓ Average time a unit spend in the system.

$$= \frac{1}{\mu - \lambda}$$

✓ Average time a unit spend in the queue.

$$= \frac{\lambda}{\mu(\mu - \lambda)}$$

✓ Average length of a non-empty queue.

$$= \frac{\mu}{\mu - \lambda}$$

✓ Probability of Number of units is at least 'n'

$$= \left(\frac{\lambda}{\mu}\right)^n$$

4.8 Simulation and Line Balancing

Simulation

Optimization Techniques	<ul style="list-style-type: none"> ➤ Techniques like Linear Programming (LPP), Transportation, and Assignment are used for solving business problems. ➤ Complex situations may require simulation for solutions.
Definition of Simulation	<ul style="list-style-type: none"> ➤ To simulate means to imitate. ➤ Involves creating a model of a real phenomenon and experimenting with it. ➤ A descriptive (not optimizing) technique.
Monte Carlo Simulation	<ul style="list-style-type: none"> ➤ A probabilistic simulation method. ➤ Involves modelling a stochastic system to predict behavior. ➤ Uses random number generators to simulate data. ➤ Useful for processes with a chance component.

4.9 Lean Operations

Roots of Lean Operation	<ul style="list-style-type: none"> ➤ Originated in Toyota Automobile Co., Japan. - Waste was avoided at all costs: <ul style="list-style-type: none"> (i) Time waste: Repairing faulty products. (ii) Inventory waste: Avoid high inventories. (iii) Idle worker waste: Minimize idle workers.
Elements of Lean Production	<ul style="list-style-type: none"> (a) View the organisation as a supply chain of value streams from suppliers to customers. (b) Organise workers into teams and ensure everyone is aware of their roles. (c) Focus on producing perfect quality and aim for continuous quality improvement. (d) Use product or cellular manufacturing instead of functional or process layouts. (e) Operate in a just-in-time (JIT) mode.

4.10 Just-In-Time (JIT)

Objectives of JIT Manufacturing	<p>The goal is to provide the right quality level at the right place based on customer demand.</p> <p>Key Objectives:</p> <ul style="list-style-type: none"> (i) Produce what customers want (goods or services). (ii) Produce only as quickly as customers need. (iii) Ensure perfect quality in production. (iv) Minimize lead times. (v) Add only the features customers want. (vi) Eliminate waste (labour, materials, equipment); avoid idle inventory. (vii) Use methods that develop worker skills.
Overview of JIT Manufacturing	<p>JIT Activities:</p> <ul style="list-style-type: none"> (i) Inventory Reduction: Reduce inventory at all stages - raw materials, work-in-progress, and finished goods. (ii) Quality Improvement: Improve quality within and outside the firm. (iii) Lead Time Reduction: Minimize set-up and move times. (iv) Vendor Control: Use fewer suppliers, focus on supplier performance (delivery, quality), and gain more power in the buyer-supplier relationship. (v) Continuous Improvement: Correct existing problems and identify new ones continuously. (vi) Total Preventive Maintenance: Prevent equipment breakdowns and reduce delays in the manufacturing process. (vii) Strategic Gain: Develop a sustainable competitive advantage in the marketplace.

Module 5. Productivity Management and Quality Management

5.1 Measurement Techniques of Productivity Index

Productivity

Definition and Concept

- Productivity is the relationship between outputs and inputs, reflecting how efficiently resources are utilized to produce goods or services.
- It represents a mindset focused on finding better, cheaper, quicker, and safer ways to perform tasks, either in manufacturing or service delivery.
- Productivity indicates the economic soundness of using production resources and measures the success of a production system.

Characteristics of Productivity

- It is the quantitative relationship between what is produced (output) and the resources used to produce it (input).
- Productivity is higher when:
 - ✓ Maximum production is achieved with minimal resource usage.
 - ✓ The ratio of outputs to inputs increases.

Measurement of Productivity

➤ Productivity Index:

- ✓ Numerically expresses the ratio between outputs and inputs.
- ✓ An upward trend in the index signals improved productivity.

➤ Symbolic Representation:

$$P = \frac{O}{I}$$

Where:

- ✓ P: Productivity.
 - ✓ O: Output (goods/services produced).
 - ✓ I: Input (raw materials, labour, machinery, power, etc.).
- Examples:
- ✓ Labour productivity: Ratio of goods produced to the number of workers or man-hours.
 - ✓ Input units can be one worker, one hour of labour, one tonne of raw material, or one kilowatt of electricity.

The importance of the concept of productivity can be viewed from the following points:

1. To Beat the Competition

Higher productivity allows firms to outperform competitors in markets with substitutes and sustain long-term existence.

2. Guide to Management

Productivity indices serve as valuable tools for improving enterprise performance.

Strategic Use

Measures and compares efficiency with competitors.- Helps in identifying steps to improve firm productivity.

Tactical Use

Assesses productivity of different units/sectors within the firm.- Enables targeted improvement for underperforming areas.

Planning

Compares benefits of different inputs to identify the most effective ones.- Aids in resource optimization for future production.

Administration

- Tracks firm progress over time.
- Measures productivity of inputs like labor individually.- Helps in negotiations with unions and governments.

3. Indicator of Progress

- Productivity improvement drives innovation and economic development.
- Promotes safer, faster, cheaper methods in production and service delivery.

4. Maximizing Resource Utilization

- Encourages optimal use of scarce resources to reduce costs and satisfy customers.
- Enhances work efficiency, reduces fatigue, and improves layouts.

5. Key to National Prosperity

- Higher productivity results in more output at lower costs.
- Enables cheaper goods, market expansion, better wages, larger profits, and economic growth.

Examples of Success

Countries like Japan, China, and South Korea thrive due to increased productivity.

6. Prosperity for Workforce

Higher productivity improves working conditions, wages, welfare, and living standards for workers.

7. Other Uses

- Boosts profits and reserves for modernization and expansion.
- Enhances goodwill through cheaper goods, better staff welfare, and strong financials.
- Strengthens export competitiveness via reduced costs and improved quality.

Conclusion

Productivity is central to national and industrial progress, benefiting businesses, workers, and the economy by enabling cost reduction, innovation, and growth.

Criteria for Measuring Productivity

1. **Change in Output per Unit of Input:** Indicates performance changes for a specific input (e.g., output per worker or per man-hour).
2. **Change in Input per Unit of Output:** Reflects performance changes for the input factor (e.g., workers or man-hours per unit of output).

Measurement Methodology

- Use standards for input factors in terms of output.
- When no standards exist, measure productivity as output per unit of input work.

Well-Known Indices of Productivity

(A) Man-hour Output

$$\text{Formula: Productivity} = \frac{\text{Units of output}}{\text{Total man-hours}}$$

(B) Productivity Ratio

Measures return on capital employed.

$$\text{Formula: Productivity} = \frac{\text{Net Profit}}{\text{Capital employed}}$$

(C) Financial Ratios

- Used where time standards cannot be set.
- Added Value Approach:

$$\text{Productivity} = \frac{\text{Added value}}{\text{Labour Costs}}$$

$$\text{productivity} = \frac{\text{Added Value}}{\text{Conversion Costs}}$$

First ratio measures financial productivity of labor; second measures all resources combined.

(D) Other Productivity Measures

$$\text{Manpower Productivity} = \frac{\text{Value of output of goods or services}}{\text{No. of workers or man-hours used}}$$

Materials Productivity

$$\text{Materials Productivity} = \frac{\text{Value of output of goods or services}}{\text{Units (or cost) of materials used}}$$

Capital Productivity

$$\text{Capital Productivity} = \frac{\text{Value of output of goods or services}}{\text{Capital assets employed}}$$

Energy Productivity

$$\text{Energy Productivity} = \frac{\text{Value of output of goods or services}}{\text{Units (or cost) of energy used}}$$

Combined Productivity

$$\text{Formula: Productivity} = \frac{\text{Value of output of goods or services}}{\text{Values of (labour + capital + materials + other inputs)}}$$

Additional Input Factors

Other inputs (e.g., insurance, taxes, advertising) can also have productivity measured similarly.

Data Availability

Accurate data for these measures is rarely available continuously for all commodities within an industry.

Tools to Increase Productivity

1. Human Aspects

- **Worker Cooperation:** Improve productivity by involving workers in management, decision-making, and communication.
- **Participation:** More worker involvement through joint consultations.
- **Trust & Cooperation:** Foster mutual trust via improved job procedures, training, incentive schemes, and labor welfare programs.
- **Better Management:** Effective planning, democratic administration, and improved human relations.
- **Personnel Selection & Training:** Enhance productivity through better recruitment and training at all levels of **management**.

2. Supply of Inputs

- **Raw Materials:** Improve the quality and timely supply of raw materials.
- **Plant & Equipment:** Ensure proper provision, maintenance, and optimal use of plant and machinery.
- **Automation:** Introduce machines and equipment to replace physical labor.

- **Utilization of Resources:** Fully utilize manpower, plant, and equipment capacity.

3. Technological Aspects

- **Work Studies:** Conduct time and motion studies to find better ways of performing tasks.
- **Simplification & Specialization:** Implement simplification, standardization, and specialization strategies.
- **Control Techniques:** Use production planning, cost control, and quality control methods.
- **Plant Layout:** Improve the layout of plants, shops, and material handling systems for better efficiency.
- **Inspection & Waste Reduction:** Enhance inspection techniques to minimize defects and wastage.

Factors Affecting Industrial Productivity

1. Technological Development

Productivity is affected by factors influencing both output and input, including:

(a) Size of the Plant

Directly impacts productivity. Inefficient plant sizes (either too large or too small) result in lower productivity.

(b) Research & Development

Investment in R&D can yield better methods, designs, and product quality, positively influencing productivity.

(c) Plant & Job Layout

Efficient arrangement of machines and worker setups can improve production speed and lower costs, enhancing productivity.

(d) Machine & Equipment Design

Modern machinery that aligns with worker capacity improves overall production efficiency and productivity.

(e) Production Processes

Advanced processes using automated machinery and semi-processed materials lead to higher productivity levels.

(f) Power & Raw Materials

Better raw materials and efficient use of power enhance productivity.

(g) Scientific Management

Techniques like better planning, time-motion studies, waste reduction, and simplified methods contribute to productivity improvements.

(h) Capital & Economic Environment

Technological development requires substantial capital investment and a conducive economic and technical environment. It influences employee performance.

2. Individual Factors

- **Knowledge:** Acquired through education, training, and interest. It increases productivity.
- **Skill:** Affected by aptitude, personality, education, experience, and training. Higher skill levels increase productivity.
- **Attitude:** The willingness of employees to work for the organization is crucial. A positive attitude leads to higher productivity.
- **Motivation:** Influenced by formal/informal organization, leadership, needs, satisfaction, and trade union influence. It drives employees to work better.

3. Organization Factors

- **Industrial Relations:** Delegation, decentralization, and participative management (e.g., worker participation in management).
- **Organizational Efficiency:** Proper personnel policies (selection, promotion, wage structure, incentives, training) and communication contribute to productivity.
- **Motivational Influence:** The presence of high-productivity goals in groups contributes to organizational objectives.
- **Hawthorne Experiments:** Found that motivated workers contribute significantly to productivity.

4. Work Environment

- **Physical Conditions:** Proper ventilation, lighting, safety, noise reduction, and rest pauses enhance productivity.
- **Psychological Factors:** Industrial psychologists emphasize the impact of work environment on productivity.

5. Other Factors

(a) Natural Factors

- **Geographical/Climatic Conditions:** Influence productivity; abundance of natural resources and climate play key roles.

(b) Managerial Factors

- **Managerial Ability:** Leadership, decision-making, foresightedness, and resource utilization significantly affect productivity.
- **Entrepreneurship:** Key for maximizing productivity through efficient resource management and organizational strategy.

(c) Government Policy

- **Government Influence:** Taxation, financial, administrative, tariff, and protection policies impact industrial productivity.

Conclusion

All these individual, organizational, environmental, and external factors play a significant role in enhancing or reducing productivity.

Production

- Refers to the volume, value, or quantity of goods and services produced within a given period by a worker, plant, firm, or economy.
- It is the total output achieved by utilizing various factors of production.

Productivity

- Not concerned with the volume of production but the ratio of output to input.
- Indicates the efficiency of production or the efficiency level of input factors.
- Relative to the resources used in generating a certain level of physical output.

Difference between Production and Productivity

- Production is used more in an absolute sense (total output), while productivity is concerned with the efficiency of inputs used to generate output.
- An increase in production does not necessarily mean an increase in productivity.
- If an increase in production is due to an increase in inputs in the same proportion, productivity may decline or remain constant.

5.2 Five Key Aspects of Productivity

Productivity

Defined as the ratio between **output volume** and the **volume of inputs**.

Measures how **efficiently production inputs** are being used in an economy to produce a given level of output.

Economic Importance

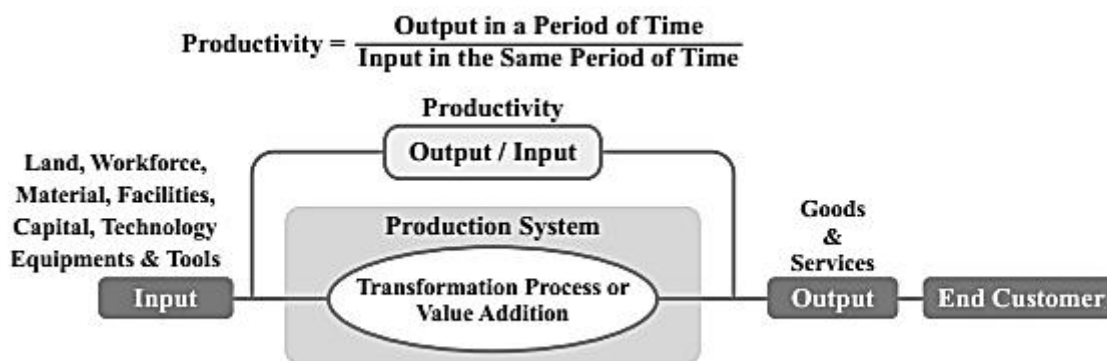
- Considered a **key source of economic growth** and **competitiveness**.
- Used for **international comparisons** and **country performance assessments**.
- Helps analyze the impact of **product and labour market regulations** on economic performance.
- Integral in determining **capacity utilization** and **forecasting economic growth**.

Challenges in Measurement

- **Output** is ambiguous due to difficulty in totaling products and services.
- **Input** involves diverse factors such as **people, capital, land, machines, etc.**

Correct Definition

- Productivity is better defined as the **relationship between results and time taken** to achieve those results.
- Example: If a carpenter completes a job in 5 hours and another in 10 hours, the first carpenter's productivity is **double** that of the second.



Employee Productivity

- Defined as the **amount of work (output)** produced by an employee in a specific period of time.
- Key to understanding how long tasks take and identifying any roadblocks.
- Important to focus on getting **important tasks done consistently** (James Clear).
- High productivity leads to better **customer service, healthier work relationships, and motivated employees**.

Ways to Measure Employee Productivity

Measure goals, measure quality of work, and measure amount of work completed.

Ways to Increase Productivity

- Improve **workplace conditions, allow flexible schedules, set clear deadlines and expectations, encourage self-care and time off, optimize meetings, and coach employees on priorities**.
- Learn **time management skills** and **boost morale** by celebrating **accomplishments**.

Material Productivity

- Vital for ensuring high effectiveness in manufacturing units.
- Materials constitute **50-70%** of total value of output.
- **Material productivity ratio:** Material output (net sales) divided by material input; ratio > 100 indicates improvement in productivity.

Land, Labour, and Capital

- These are basic inputs but need to be **brought together** by competent management.
- **Management** is the key to productivity—competent managers can optimize human and technical resources.
- Even with advanced technology and trained workers, **inefficient management** can result in low productivity.

Managerial Role

A **competent manager** is crucial to achieving high productivity through optimal resource utilization and leadership.

Other Factors Impacting Productivity

Technological Factors

Factors such as **product design, plant layout, size and capacity of plant, location of plant, timely supply of raw materials, repairs and maintenance, and R&D** all influence productivity.

Natural Factors

Physical, geographical, geological, and climatic conditions can **significantly impact productivity**, especially in industries with extraction activities.

Social Factors

Social norms, culture, and customs impact productivity, and these vary by location (e.g., **India vs. Japan or USA**).

Political Factors

Stable **law and order, government stability, industrial policies, and taxation policies** are necessary to improve productivity.

Economic Factors

Factors like **market size, banking and credit facilities, and transportation** influence productivity.

Organizational Efforts

- Strive to create a **climate of interest and passion** for efficiency and resource utilization.
- **Productivity improvement** leads to higher revenues, allowing for **better technology** and improved business performance.

5.3 TQM Basic Tools and Certification

Total Quality Management

A philosophy that involves everyone in an organisation in a continual effort to improve quality and achieve customer satisfaction.

Basic Concepts in TQM

1. Top management commitment and support.
2. Focus on both internal and external customers.
3. Employee involvement and empowerment.
4. Continuous improvement (KAIZEN)
5. Partnership with suppliers
6. Establishing performance measures for processes.

Essentials of TQM Focus

1. Customer satisfaction
2. Leadership
3. Quality policy
4. Organisation structure
5. Employee involvement

6. Quality costs
7. Supplier selection and development
8. Recognition and reward.

Underlying Principles in TQM

1. Strive for quality in all things (Total Quality)
2. The customer is the creation of quality
3. Improve the process or systems by which products are produced
4. Quality improvement is continuous, never ending activity (continuous improvement-Kaizen)
5. Worker involvement is essential
6. Ground decisions and actions on knowledge
7. Encourage team work and cooperation.

Scope of TQM

1. An integrated organisational infrastructure
2. A set of management practices
3. A wide variety of tools and techniques.

TQM (Total Quality Management)

- Japanese approach to quality management.

Definition of TQM

- TQM refers to a quest for quality in an organization.

Key Philosophies of TQM

1. Continuous improvement: A never-ending push to improve.
2. Involvement of every employee: Every individual contributes to quality.
3. Customer satisfaction: Meeting or exceeding customer expectations.

Focus Areas of TQM

Benchmarking world-class standards, product and service design, and purchasing.

Elements of TQM

- Team approach: Collaboration across the organization.
- Employee empowerment: Employees have the authority to make decisions.
- Fact-based decisions: Decisions should be based on data and facts rather than opinions.
- Knowledge of quality tools: Use of tools like flow charts, check sheets, histograms, Pareto analysis, scatter diagrams, etc.
- Quality at the source: Ensuring quality at each stage of production.
- Supplier involvement: Including suppliers in the quality improvement process.

TQM Process

- TQM involves continuous improvement at every level of the organization.
- Customer satisfaction is the center of the process, aiming to improve quality at all stages—from customer demands to product design to engineering.

Communication and Integration

- TQM aims to break down communication barriers between employees and between the organization and external stakeholders.
- It seeks to increase cross-functional integration and cooperation to improve quality.

TQM as a Culture

TQM is not just a collection of techniques; it reflects a new attitude toward quality and requires a change in organizational culture.

Cooperative Relationships

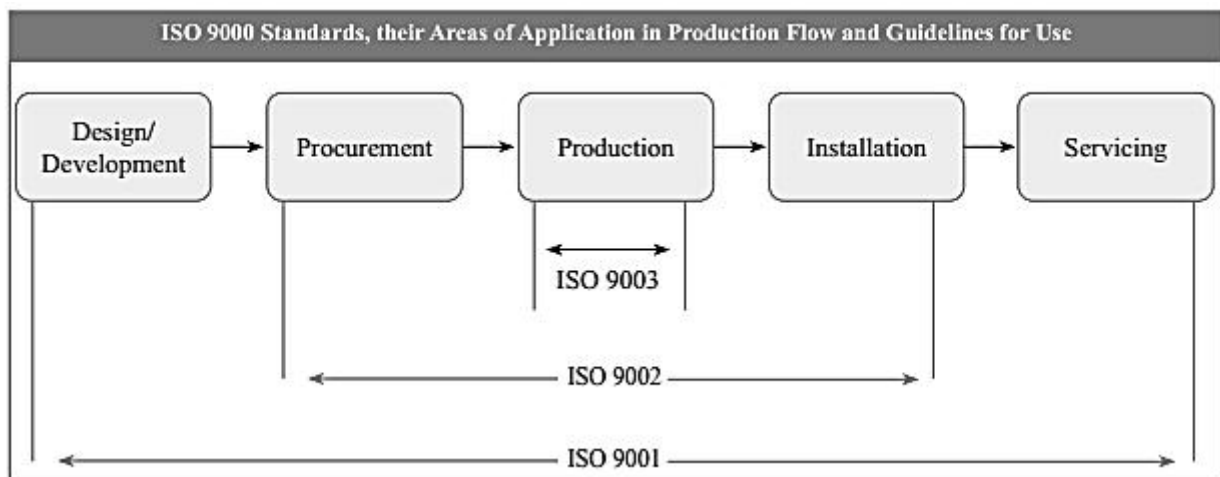
TQM organizations strive to develop cooperative relationships with suppliers and distributors to align continuous improvement of quality as a shared goal.

Examples of TQM Implementation

Companies like **Ford**, **Motorola**, and **GM** have developed long-term relationships with suppliers and distributors for continuous quality improvement.

5.4 ISO Standard Basics

Quality Certification	Quality certification is recognized by international businesses as essential for ensuring consistent product/service quality.
ISO Certification	ISO 9000 and ISO 14000 are two well-known quality certifications established by the International Organisation for Standardisation (ISO) .
ISO 9000	ISO 9000 focuses on quality management to ensure products and services meet customer expectations.
ISO 14000	ISO 14000 focuses on minimizing harmful environmental effects caused by the organization's operations.
Scope of ISO 9000 and 14000	Both ISO 9000 and 14000 focus on organizational processes rather than the final products or services, emphasizing continuous improvement .
Global Adoption of ISO 9000	ISO 9000 is composed of 91 countries' national standard bodies , with about 90 countries adopting it as national standards.
Purpose of ISO Certification	The certification aims to promote quality at every level of an organization, ensuring adherence to quality standards throughout the production process.
ISO Certification Process	
<ul style="list-style-type: none"> ➤ ISO certification is elaborate and expensive. ➤ A firm must document how workers perform functions affecting quality and install mechanisms to ensure compliance. ➤ ISO 9000 certification evaluates management systems and procedures rather than just the quality of products, analyzing everything from purchasing to training. ➤ A firm must submit a report and be certified by independent auditors, then gets registered in an ISO directory. 	
Benefits of ISO Certification	Firms in the ISO directory are preferred over unregistered firms, enhancing supplier relationships .
ISO 9000 Series Standards	
<ul style="list-style-type: none"> ➤ ISO 9000 series has five primary standards, which vary in their focus from design to final servicing. ➤ The standards range from design and development, procurement, production, installation, and servicing. 	
ISO 9001	Model for Quality Assurance in Design, Production, Installation, and Servicing . Used when conformance to specified requirements is to be assured during multiple stages of production and servicing.
ISO 9002	Model for Quality Assurance in Production and Installation . Used when conformance to specified requirements is assured during production and installation .
ISO 9003	Model for Quality Assurance in Final Inspection and Test . Used when conformance is ensured only during the final inspection and test .
ISO 9000 (Guidelines for Use)	Provides guidelines for selecting and using the appropriate quality management and quality assurance standards.



ISO certification is a must for doing business with any member of the EU. In addition to the benefits of accessing the EU, ISO 9000 certification and registration is particularly helpful for companies that do not currently have a quality management system, as it provides guidelines for establishing the system and making it effective. The latest version of ISO 9000 forms the basis of eight quality management principles

1. A system approach to management
2. Continual improvement
3. Factual approach to decision making
4. Mutually beneficial supplier relationships
5. Customer focus
6. Leadership
7. People involvement
8. Process approach

ISO standards are reviewed every five years and revised if needed. This helps ensure they remain useful tools for market place. The challenges faced by business and organisations today are very different from few decades ago and ISO 9001 has been updated to take this new environment into account.

The last version was ISO 9001: 2008 and has been replaced by further updated version ISO 9001: 2015 on and from September 2018.

Module 6. Project Management, Monitoring and Control

6.1 Project Planning

Project Management

- Utilizes tools like Gantt charts to plan and track progress.
- Focuses on completing projects within scope, quality, time, and cost constraints.
- Projects differ from ongoing operations; they are temporary and unique.

Key Challenges

- Delivering within defined constraints (time, cost, quality).
- Optimizing resource allocation and integration to meet objectives.

Project Scope

- Defined scope helps determine completion methods.
- Tasks are listed and grouped into a work breakdown structure.
- Critical paths are identified using activity network diagrams.

Project Costs and Baseline

- Resources and costs are estimated for activities.
- Plans are optimized for resource use and duration balance.
- The agreed plan becomes the baseline for tracking progress (Earned Value Management).

Gantt Chart

- Tool for scheduling and loading tasks.
- Time is represented horizontally; tasks are listed vertically.
- Shows progress using bars/lines proportionate to work completed.
- Divided into Work Schedules and Load Charts.

Network Analysis

- Routing determines the sequence of operations.
- Suitable for both small and large projects (requires more study for larger projects).
- Network diagrams map activities, durations, and dependencies.

Important Characteristics in Network Analysis

- Objective: Complete the project within the specified time to avoid penalties.
- Activities must be completed in a defined order; some can occur simultaneously, while others depend on prior activities.
- Cost of activities is proportional to their completion time.
- Hurdles may arise, and resources may be limited.
- A network graph consists of nodes (points) and edges (routes), representing operations and activities.
- Represents the time orientation of a composite project.

Network Drawing

- Graphically depicts all operations in a project.
- Maintains relationships between various activities.

Key Terminologies

Activity:

An activity is a task associated with a project. It is a physically identifiable part that consumes time and resources.

Example: Laying a pipeline is an activity.

➤ Representation: Represented by an arrow in project diagrams.

Cannot begin until predecessor activities are completed.

Predecessor Activity: Must be completed before another activity starts.

Successor Activity: Starts after one or more preceding activities are completed.

Concurrent Activities: Activities that occur simultaneously.

Dummy Activity

A task that does not take time or resources but is necessary for project documentation and sequence.

Example: Adding a dummy task to denote dependency between two tasks.

Event

An event signifies the start or completion of activities.

➤ Tail Event: Marks the beginning of an activity.

Example: In the activity "2 to 3," 2 is the tail event.

➤ Head Event: Marks the end of an activity.

Successor and Predecessor Event

➤ Successor Event: Events that follow an event.

➤ Predecessor Event: Events that occur before an event.

Earliest Event Time (EET)

The earliest time an event can occur.

➤ Notation: E2 for the earliest occurrence of event 2.

Latest Event Time (LET)

The latest time an event must occur to keep the project on schedule.

➤ Notation: L2 for the latest occurrence of event 2.

Earliest Start Time (EST)

The earliest time an activity can start.

Example: For activity "2 to 3," EST is E2.

Earliest Finish Time (EFT)

The earliest time an activity can finish.

➤ Calculation: $EFT = EST + \text{Duration}$

Latest Finish Time (LFT)

The latest time an activity can finish without delaying the project.

Example: For activity "2 to 3," LFT must not delay project completion.

Latest Start Time (LST)

The latest time an activity can start without delaying the project.

➤ Calculation: $LST = LFT - \text{Duration}$

Total Float

The total amount of time an activity can be delayed without affecting the project end date.

➤ Calculation: $\text{Total Float} = LFT - EFT$ or $\text{Total Float} = LST - EST$

Free Float

The amount of time an activity can be delayed without affecting the early start of succeeding activities.

➤ Calculation: $\text{Free Float for activity "2 to 3"} = E3 - E2 - \text{Duration}$

Independent Float

The amount of time an activity can be delayed without affecting preceding and succeeding activities.

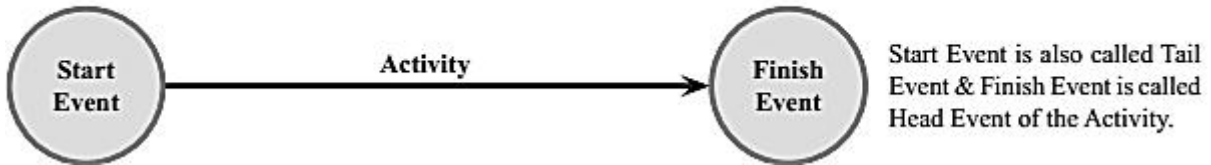
➤ Calculation: $\text{Independent Float for activity "2 to 3"} = E3 - L2 - \text{Duration}$

Critical Path

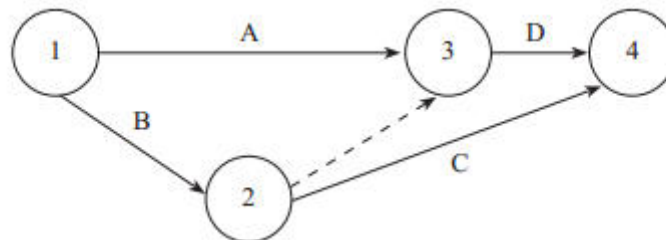
The sequence of activities that determines the total project time. The longest path in terms of duration.

Example: In a project with multiple paths, the one with the longest duration is the critical path.

All Activity arrows must begin and end with Event nodes as shown below :-



Merge Event	An event where more than one activity ends. Examples: In a diagram, nodes 3 and 4 can be Merge Events.
Burst Event	An event where more than one activity starts. Examples: In a diagram, nodes 1 and 2 can be Burst Events.
Merge and Burst Events	<ul style="list-style-type: none"> ➤ Events where multiple activities end, and multiple activities start. ➤ A combination of Merge and Burst Events.
Dummy Activity	<ul style="list-style-type: none"> ➤ Used to distinguish activities with common start and end events or maintain proper precedence relationships. ➤ Represents activities that consume no time or resources. ➤ Depicted as dashed arrows in network diagrams.
Purpose of Dummy Activities	<ul style="list-style-type: none"> ➤ Makes activities with common start and end events distinguishable. ➤ Maintains the proper precedence relationship between unrelated activities.
Example of Dummy Activities	For concurrent activities (e.g., A and B), if C depends on B and D depends on both A and B, a Dummy Activity is introduced to represent this precedence.



Critical Path Method (CPM)

- Tool for production planning and scheduling.
- Identifies the longest sequence of activities (critical path) to minimize project completion time.
- Critical activities require priority attention to avoid delays.
- CPM marks critical activities and provides a schedule to optimize performance.

PERT (Program Evaluation and Review Technique)

- Time-event network analysis technique developed by the U.S. Navy in 1958.
- Assumes that expected time of operations cannot be precisely determined.
- Used in industries like defense, chemical, and construction for planning and control of large projects.

Major Features of PERT	<ul style="list-style-type: none"> ➤ All individual tasks are represented in a network. ➤ Events: Represented by circles, each denoting a measurable subsidiary plan completed at a specific time. ➤ Activities: Represented by arrows, denoting time-consuming elements between events.
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Activity Time

Definition: Elapsed time required to accomplish an event. - Three time estimates are used:

1. **Optimistic Time (t₁):** Best estimate if everything goes exceptionally well.
2. **Most Likely Time (t₂):** Time most often required if activity is repeated several times, as per project engineer's estimate.
3. **Pessimistic Time (t₃):** Estimate of time under adverse conditions; represents the longest time, often challenging to determine.

The experiences have shown that the best estimator of time out of several estimates made by the project engineer is:

$$T = \frac{t_0 + 4t_m + t_p}{6} \text{ and the variance of } t \text{ is given by: } V(t) = \Sigma \left(\frac{t_p - t_0}{6} \right)^2$$

4. The next step is to compute the critical path and the slack time

A critical path or critical sequence of activities is one which takes the longest time to accomplish the work and the least slack time.

	PERT (Program Evaluation and Review Technique)	CPM (Critical Path Method)
Time Estimates	➤ Three Time Estimates: Uses optimistic, pessimistic, and most likely time estimates.	➤ Single Time Estimate: Uses one specific time estimate for each task.
Focus	Concerned with events , which are the beginning or ending points of operations.	Concerned with activities , which are time-consuming elements of the project.
Project Type	Suitable for non-repetitive projects.	Designed for repetitive projects.
Statistical Analysis	Can be analysed statistically.	Cannot be analysed statistically.
Time-Cost Relationship	Does not establish a relationship between time and cost.	Establishes a relationship between time and cost, where cost is proportionate to time.

6.3 Gantt Charts

Gantt Chart Overview	<ul style="list-style-type: none"> ➤ Graphical representation of activities on a time scale. ➤ X-axis: Represents time. ➤ Y-axis: Represents activities. ➤ Horizontal bars show the start and completion dates of activities. ➤ Also known as a "bar chart."
Strengths of Gantt Charts	<ul style="list-style-type: none"> ➤ Simple to understand by all stakeholders (foremen, engineers, managers, etc.). ➤ Easy to develop and interpret.

	<ul style="list-style-type: none"> ➤ Useful for planning and monitoring project progress. ➤ Helps evaluate progress at various levels. ➤ Facilitates resource allocation, including manpower and equipment adjustments. ➤ Flexible for incorporating changes in timing and machine loads. ➤ Suitable for various formats (e.g., ruled paper, mechanical devices, computer systems).
Limitations of Gantt Charts	<ul style="list-style-type: none"> ➤ Does not show variability in task duration, equipment performance, or human potential. ➤ Lacks details about progress of activities. ➤ Does not indicate interrelationships between activities. ➤ Static representation requiring periodic updates.

6.5 Basics of MS Project

Microsoft Project Overview

- A project management software by Microsoft.
- Assists in:
 - ✓ Developing schedules.
 - ✓ Assigning resources to tasks.
 - ✓ Tracking progress.
 - ✓ Managing budgets.
 - ✓ Analyzing workloads.

Budget and Costing

- Budgets are based on assignment work and resource rates.
- Costs are calculated as $\text{Work} \times \text{Rate}$ and roll up from task level to summary tasks, and then to project level.

Resource Management

- Resources have individual calendars defining availability (days and shifts).
- Not suitable for managing materials-constrained production; additional software is required for complex facilities producing physical goods.

Project Management with MS Project

- Helps create schedules within provided constraints.
- Cannot replace planning; project managers must develop plans considering:
 - ✓ Scope: Tasks and their order.
 - ✓ Time: Constraints and deadlines.
 - ✓ Resources: Man/machine/material needed.
 - ✓ Cost: Task-specific costs.
 - ✓ Risk: Associated risks affecting scope, cost, and time.

Module 7. Economics of Maintenance and Spares Management

7.1 Breakdown Maintenance

Maintenance Approach	The facility operates without routine maintenance until a machine breaks down.
Process Post-Breakdown	<ul style="list-style-type: none"> ➤ Machine is taken for repair. ➤ Inspected to identify defects. ➤ Required repairs are planned. ➤ Spare parts are procured for the repair.
Consequences of Breakdowns	<ul style="list-style-type: none"> ➤ Random nature of breakdowns leads to unpredictability. ➤ Machines remain idle during the repair, causing lost production hours and reduced productivity.
Perception of Repair Maintenance	<ul style="list-style-type: none"> ➤ Organizations prefer avoiding machine downtime for maintenance. ➤ Repair maintenance appears economical for specific non-critical items.
Costs and Implications	<ul style="list-style-type: none"> ➤ Breakdown repairs cost more than regular maintenance. ➤ Economical for items where repair and downtime costs are lower compared to regular maintenance.
General Recommendation	Repair maintenance is not generally recommended but is practical for certain non-critical equipment.

7.2 Preventive Maintenance

Overview of Preventive Maintenance

- Preventive maintenance aims to reduce breakdowns by locating weak parts in equipment and conducting regular inspections and minor repairs.
- The principle is "prevention is better than cure."
- Involves periodic inspections to identify conditions leading to breakdowns and harmful depreciation.
- The system varies between plants based on specific requirements.

Key Benefits

- Reduces unanticipated breakdowns.
- Increases equipment availability for production.
- Maintains optimal productive efficiency of equipment and machinery.
- Reduces maintenance workload.
- Improves productivity and worker safety.

7.3 Routine Maintenance

Maintenance Techniques

1. Running Maintenance:

- Involves tasks like lubrication, cleaning, and periodic overhauls while the equipment is running or during planned shutdowns.

Maintenance Organization

1. Significance:

- Effective maintenance is essential as 50-60% of organizational investment is in buildings and production facilities.

2. Key Principles for Maintenance Organization:

- Clear division of authority with minimal overlap.
- Short vertical lines of authority and responsibility.
- Span of control for managers should range between 3 to 6.
- Flexible organizational structure tailored to specific maintenance requirements.
- Maintenance can be centralized or decentralized depending on the plant's needs.

Predictive Maintenance

Definition: This advanced maintenance strategy uses data analytics and monitoring technologies to predict when equipment will fail. Maintenance tasks are performed just before the predicted failure.

Example: In a power plant, sensors monitor the condition of turbines in real-time. Data analytics predict when a turbine is likely to fail, allowing maintenance to be scheduled before the failure occurs.

Importance of Maintenance Records

- Maintenance records are vital for effective maintenance but are often neglected.
- Detailed records, such as history cards or logbooks for each piece of equipment, must include:
 - ✓ Materials used.
 - ✓ Components replaced.
 - ✓ Time spent on repairs.
- Proper record-keeping aids in planning, control, and efficient maintenance.

Significance of Preventive Maintenance

- Preventive maintenance is effective when:
 - ✓ The average downtime and costs from breakdown repairs exceed the time and costs for preventive actions.
 - ✓ Repairs can be scheduled during planned idle times, avoiding production disruptions.
- Especially critical in production lines, where a single machine breakdown can halt the entire operation.

7.4 Replacement of Machine

Causes for Machinery Replacement

1. **Wear and Tear:**
 - Normal usage and passage of time lead to wear and tear.
 - Reducing wear is a key focus in machinery design.
2. **Technological Obsolescence:**
 - Machines become obsolete when newer models perform tasks more efficiently, quickly, and at lower costs.
 - The fast rate of technological advancements often necessitates replacing machinery before its expected life.
 - Obsolescence affects procurement and installation decisions, as older machines may become uneconomical.

7.5 Spare Parts Management

Summary of Spare Parts Management (SPM)

Overview

- Spare Parts Management (SPM) is a critical activity in large manufacturing plants, ensuring better service during the product lifecycle.