

CMA INTER

P9A OPERATIONS MANAGEMENT

CONCEPT BOOK & QUESTION BANK





Preface

Let's Crack It - Operations Management Knowledge Pack

By Prof. Asif Pazheri

The Operations Management Knowledge Pack is crafted as a vibrant, learner-centric resource tailored for CMA Intermediate students. This color concept book is not merely a theoretical outline—it's a strategic toolkit designed to simplify, reinforce, and elevate your understanding of core OM principles through visual clarity and practical engagement.

With expertly designed charts, mnemonics, and highlighted key points, this book transforms complex topics into digestible insights. It bridges academic rigor with exam readiness, offering a structured pathway to mastering Operations Management. Each concept is supported by a curated Practice Question Bank and MCQ section, enabling students to test their grasp, sharpen analytical thinking, and build exam confidence.

This resource reflects the teaching philosophy of Prof. Asif Pazheri—methodical, student-focused, and committed to excellence. Whether you're decoding process layouts or optimizing supply chains, this pack ensures you're not just prepared—you're empowered.

"Success is not an accident. It's the result of deliberate preparation, persistent effort, and strategic learning."

Let's crack it.

#0A6847 - Headings

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MODULE 1. INTRODUCTION

1. Scope

Simplified Explanation	
1.	Definition Operations Management (OM) covers all organizational activities that take raw materials (input) and turn them into products and services.
2.	Process It involves processing or converting materials into consumable outputs that meet customer needs.
3.	Scope OM applies to both tangible products and intangible services.

Activities in Operations Management

Core Task	
1.	Input Acquisition Getting raw materials, labour, equipment, and information needed for operations.
2.	Transformation Process Converting inputs into outputs through manufacturing, service delivery, or both.
3.	Output Delivery Distributing finished goods or services to customers.
4.	Feedback & Control Monitoring performance and making adjustments to improve efficiency and quality.

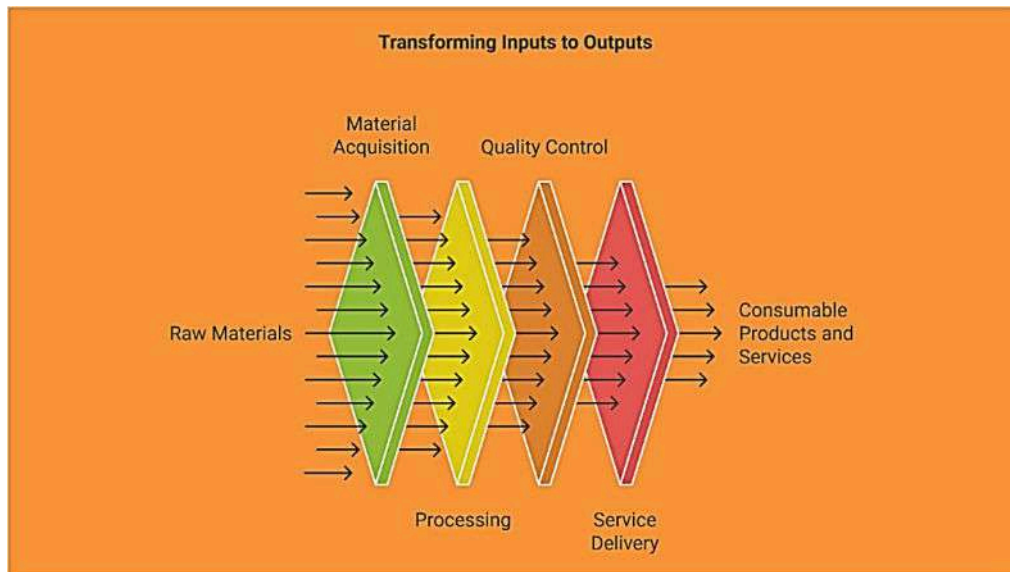
Scope of Operations Management

Domain / Function	
1.	Manufacturing Focuses on production planning, inventory control, and quality assurance.
2.	Service Delivery Involves scheduling, customer interaction, and service design.
3.	Supply Chain Management Handles suppliers, logistics, and distribution.

Joint Occurrence: Goods and Services

OM doesn't just handle physical products—it also manages services. Often, they occur together:

Type	Description	Example
Goods	Tangible items produced and consumed	A smartphone, a car, packaged food
Services	Intangible experiences or outcomes	Banking, education, healthcare
Combined	Goods with embedded services or vice versa	A restaurant (food + service), airline travel (transport + hospitality)



■ The Twin Objectives of Operations Management

Objective	Simplified Explanation	Key Aspects
Customer Service	Main goal is customer satisfaction by delivering goods/services that meet wants and expectations .	• Specification: Match customer requirements • Cost: Offer at the right price • Timing: Deliver at the right time
Resource Utilization	Ensure efficient use of resources (materials, labour, equipment, time) to support customer service. Poor use of resources or weak service can lead to failure .	Focus: Efficiency + Effectiveness

📷 Snapshot: Real-World Examples of the Twin Objectives

🔧 Objective 1: Customer Service

Aspect	
1.	Specification A custom-fit suit tailored to the customer's measurements and style
2.	Cost Budget airline offering low fares with essential services
3.	Timing Amazon Prime delivering packages within 24 hours

⚙️ Objective 2: Resource Utilization

Resource Type	
1.	Human Resources A hospital scheduling nurses based on patient inflow patterns
2.	Material Resources A car manufacturer using just-in-time inventory to reduce waste
3.	Technological

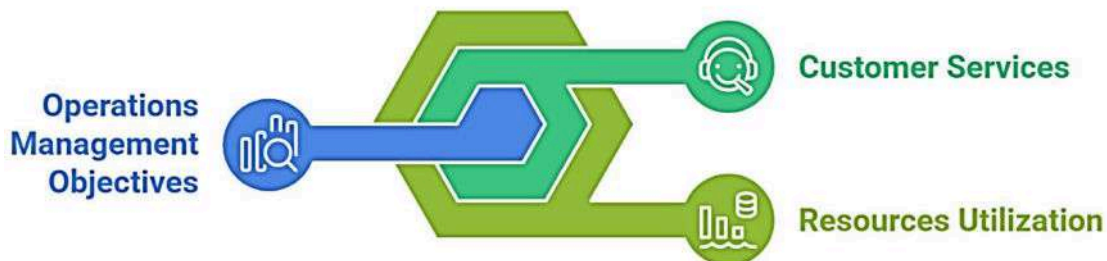


A cloud service provider optimizing server usage during peak hours

☀️ Stunning Points to Remember

Point	Simplified Statement
✓ Customer Satisfaction	Not optional—it's the heartbeat of operations.
📦 Efficiency & Effectiveness	Must go together for sustainable success .
⚙️ Operations Management	A balance: delight customers while saving resources .

Objectives of Operations Management



■ The Four Principal Functions of Operations Management

Principal Function	Primary Consideration	Other Considerations
Manufacture	Goods of a specific, requested, or acceptable quality.	- 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.	Cost: Expense of transportation 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.	- 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.	- Cost: Expense of the treatment or service - Timing: 1. Duration or time required for the treatment 2. Wait or delay from request to start.

🎯 Reference to the Three Aspects of Customer Service

Aspect	Focus	Meaning
Specification	What	Delivering what the customer actually wants.
Cost	How Much	Offering it at a price the customer finds acceptable.
Timing	When	Providing it when the customer needs it.

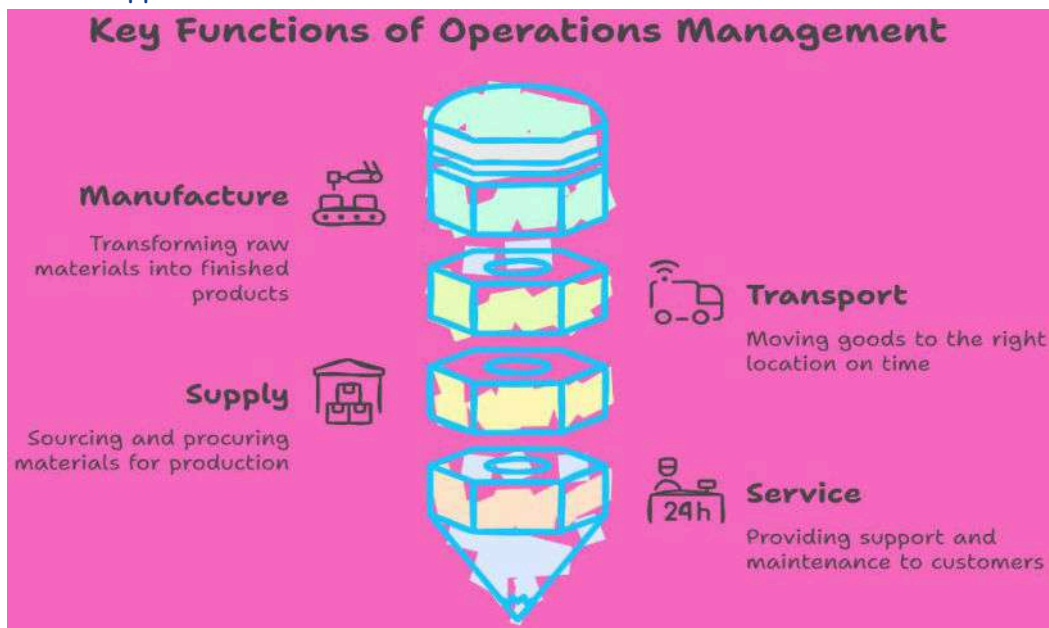
🏠 Real-World Examples



Function	Specification Example	Cost Example	Timing Example
Manufacture	Producing eco-friendly packaging for a brand	Using recycled materials to reduce production cost	Delivering seasonal products before peak demand
Transport	Shipping fragile goods with proper handling	Choosing cost-effective logistics partners	Ensuring overnight delivery for urgent orders
Supply	Supplying fresh produce to restaurants	Bulk purchasing to reduce unit cost	Daily supply to meet freshness standards
Service	Providing personalized banking advice	Offering tiered pricing for different service levels	Scheduling appointments with minimal wait time

Mnemonic to Remember the Four Functions: "MTSS" - Make Things Smooth & Swift"

- M** - Manufacture: Create the product
- T** - Transport: Move the product
- S** - Supply: Provide the product
- S** - Service: Support the customer



Scope of Operations Management

	Concept
1.	Operations Management Concerned with the conversion of inputs into outputs using physical resources .
2.	Objective Provide the desired utilities to the customer while ensuring effectiveness, efficiency, and adaptability for the organization.
3.	Functions Include various activities under Production and Operations Management .



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.

Concept Breakdown with Simple Examples

Function	Explanation	Example
1. Location of Facilities	Choosing the best geographic site for operations based on cost, access, and demand.	A company sets up its factory near a port to reduce shipping costs.
2. Plant Layouts & Material Handling	Designing the physical arrangement of equipment and workflow; managing movement of materials.	A bakery places ovens close to the prep area to reduce movement and save time.
3. Product Design	Creating products that meet customer needs and are feasible to produce.	A smartphone company designs a sleek, lightweight phone with a long battery life.
4. Process Design	Planning the steps and technology used to produce goods or services.	A clothing brand uses automated sewing machines to speed up production.
5. Production Planning & Control	Scheduling and monitoring production to meet demand efficiently.	A toy manufacturer plans extra shifts before Christmas to meet seasonal demand.



6. Quality Control	Ensuring products/services meet defined standards and customer expectations.	A car company checks every vehicle for safety before shipping.
7. Materials Management	Managing inventory, procurement, and storage of raw materials.	A restaurant tracks its daily vegetable stock to avoid spoilage and shortages.
8. Maintenance Management	Keeping equipment and facilities in working condition to avoid downtime.	A hospital regularly services its MRI machines to ensure reliability.

✳ Mnemonic: "Linear Programming Paranthu Padichath QMM"

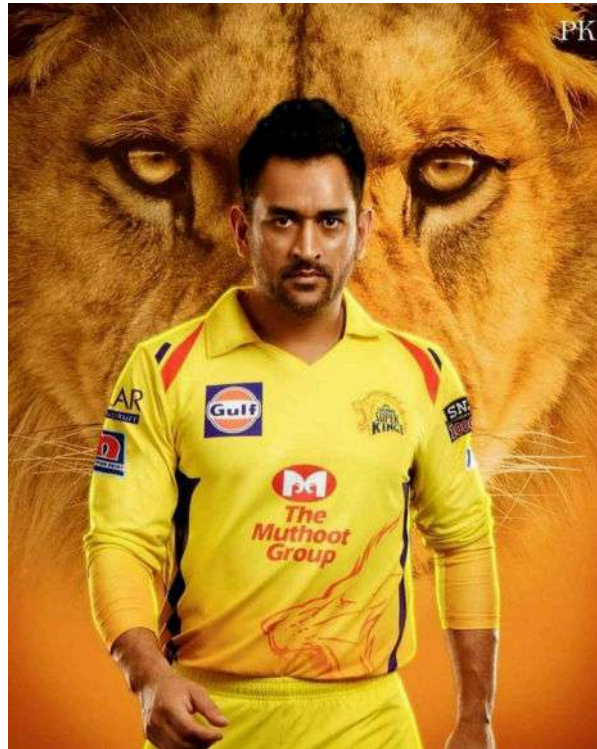
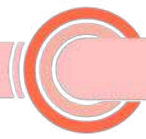
1.Characteristics of Modern Operations Functions

Content	
1.	Manufacturing as Competitive Advantage 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.
2.	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.
3.	Disappearance of Smokestacks Modern factories are aesthetically designed, environmentally friendly, and have transformed into knowledge-based organizations. Going to work has become a more pleasant experience.
4.	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.

✦ Real-World Examples

🧠 Mnemonic: "M.S.D.S. - MS Dhoni Singham Daal!"

Theme	Key Insight	Example
 Manufacturing as Competitive Advantage	Production is now a strategic weapon .	Toyota : Just-In-Time (JIT) & Total Quality Management (TQM) helped dominate global auto markets.
 Services Orientation	Operations must adapt to service traits like perishability & customization .	Airbnb : Ensures local responsiveness & personalized experiences.
 Disappearance of Smokestacks	Factories are now green & smart instead of grimy.	Tesla Gigafactories : Solar energy + AI-driven automation.
 Small has Become Beautiful	Local, community-driven production is on the rise.	Microbreweries & organic farms thriving via community support.



- **M** - Manufacturing as Competitive Advantage
- **S** - Services Orientation
- **D** - Disappearance of Smokestacks
- **S** - Small has Become Beautiful



1.Recent Trends in Production and Operations Management

Distinction Between Production Management and Operations Management

■ Production Management vs Operations Management

Point of Distinction	Production Management	Operations Management
Scope	Mainly used for systems where tangible goods are produced.	Used when various inputs are transformed into intangible services (e.g., banks, airlines, utilities, education, consultancy, police , etc.), in addition to manufacturing.
Evolution	Preceded operations management in the historical growth of the subject.	Modern term used today, reflecting a broader scope beyond just production.

Recent trends in production and operations management relate to **global competition** and the impact it has on manufacturing firms. Some of the recent trends are:

🧠 Key Distinctions - Simplified

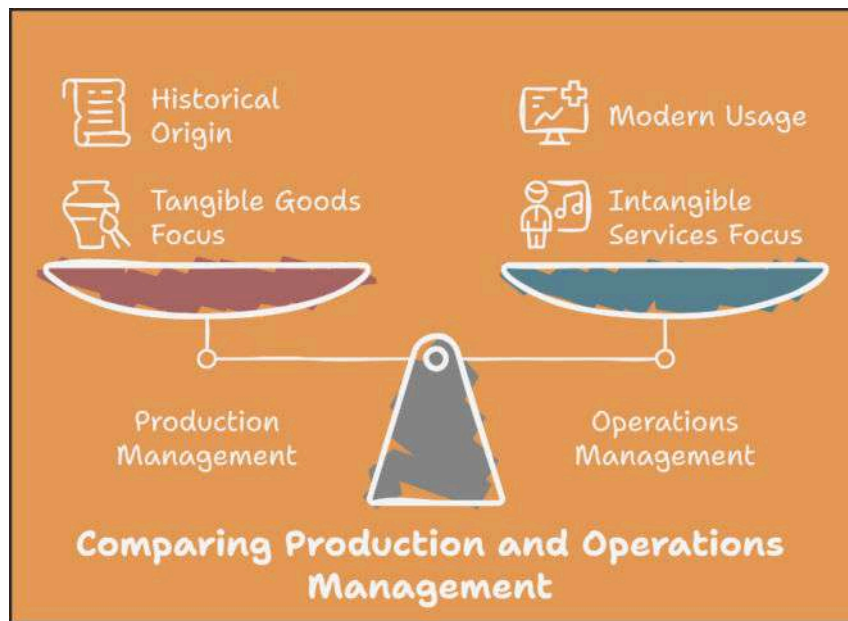
Aspect	Production Management	Operations Management
Focus	Tangible goods	Tangible goods + Intangible services
Scope	Manufacturing units	Manufacturing + Service organizations
Terminology Usage	Traditional term	Modern, evolved term
Examples of Application	Factories, assembly lines	Banks, hospitals, airlines, universities, consultancies

🏠 Real-World Examples

Function Type	Example
Production Management	A car manufacturer managing assembly line efficiency and output quality.
Operations Management	A hospital optimizing patient flow, staff scheduling, and service delivery.
Production Management	A textile mill planning fabric production and inventory.
Operations Management	An airline coordinating ticketing, baggage handling, and flight operations.

💡 Stunning Points to Remember

- ☑ **Production Management is a subset of Operations Management.**
- 🔗 **Operations Management is broader—it includes services, strategy, and adaptability.**



■ Chapter: Recent Trends in Production and Operations Management

Global competition has reshaped how manufacturing and service firms operate. The following 12 trends reflect the strategic, technological, and human-centered shifts in modern operations.

🔑 Key Trends

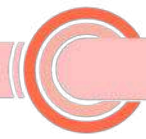
Content		
1.	🌐	Global Market Place Globalization pushes firms to operate in multiple countries; increases international competition and the need for globally competitive operations.
2.	🎯	Production/Operations Strategy Aligns operational decisions with business strategy; operations as a strategic tool for long-term success.
3.	✅	Total Quality Management (TQM) Continuous improvement to achieve customer satisfaction; a long-term commitment to excellence across the organization.
4.	🔄	Flexibility (Agile Manufacturing) Ability to adapt quickly to demand, product mix, design, and delivery changes; provides responsiveness and competitive edge.
5.	⌚	Time Reduction Shortening manufacturing cycles and speeding product launches; faster delivery gives market advantage.
6.	💻	Technology Integration Use of automation, computerization, ICT to transform operations and enhance productivity.
7.	👥	Worker Involvement Empowering employees in decision-making and problem-solving; boosts morale, innovation, and accountability.

8.		Re-engineering Radical redesign of business processes for better efficiency, speed, and results; a clean-slate approach.
9.		Environmental Issues Focus on pollution control, waste reduction, recycling, and eco-friendly production.
10.		Corporate Downsizing (Right Sizing) Reducing workforce/operations to become leaner and more efficient; helps firms focus on core strengths.
11.		Supply-Chain Management Optimizing the flow of goods from suppliers to customers; reduces costs and improves efficiency and customer satisfaction.
12.		Lean Production Producing high-quality goods with minimal resources; combines speed of mass production with customization.

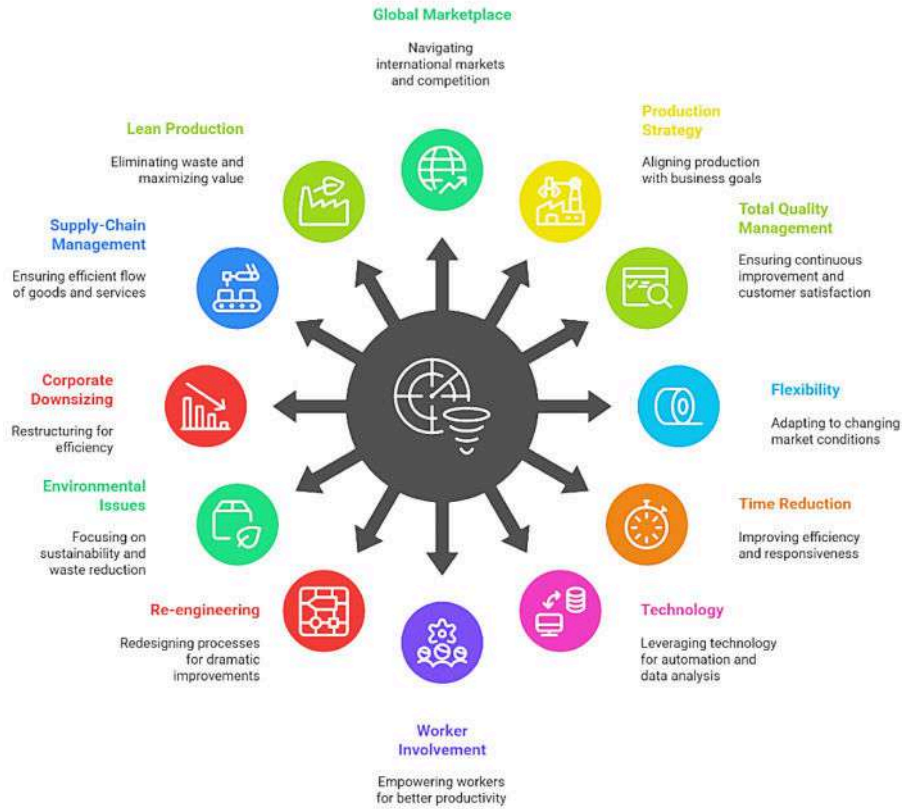
 Mnemonic Phrase

"Great People Try Finding Time To Work Really Effectively Even During Stressful Long Shifts."
Each word stands for:

Mnemonic Word	Trend
Great	Global Market Place
People	Production Strategy
Try	Total Quality Management (TQM)
Finding	Flexibility
Time	Time Reduction
To	Technology
Work	Worker Involvement
Really	Re-engineering
Effectively	Environmental Issues
During	Downsizing (Corporate)
Stressful	Supply-Chain Management
Long Shifts	Lean Production



Operations Management Trends



MODULE 2 OPERATIONS PLANNING

1. Demand Forecasting

Forecasting -

Concept	Explanation	Focus Area
 Forecasting	Predicting future events or needs using available data and trends.	 Demand Forecasting: Estimating future product demand—how much customers will need.

Why Is Forecasting Important?

1.	Production & Resource Planning Helps companies plan production, manage inventory, and allocate resources efficiently.
2.	Demand-Supply Balance Ensures supply matches demand, avoiding shortages or excess stock.
3.	Decision Support Supports better decision-making in operations.

Key Points to Remember

1.	Forecast Definition A forecast is an estimate of a future value, e.g., expected sales or demand.
2.	Competitive Advantage Accurate forecasting provides firms with a competitive edge.
3.	Operational Efficiency Essential for efficient operations, cost control, and customer satisfaction.

Real-Life Examples

1.	Clothing Brand Predicts demand for winter jackets using past sales and weather trends.
2.	Hospital Forecasts patient admissions to prepare staff and supplies.
3.	Smartphone Company Estimates demand for a new model before product launch.

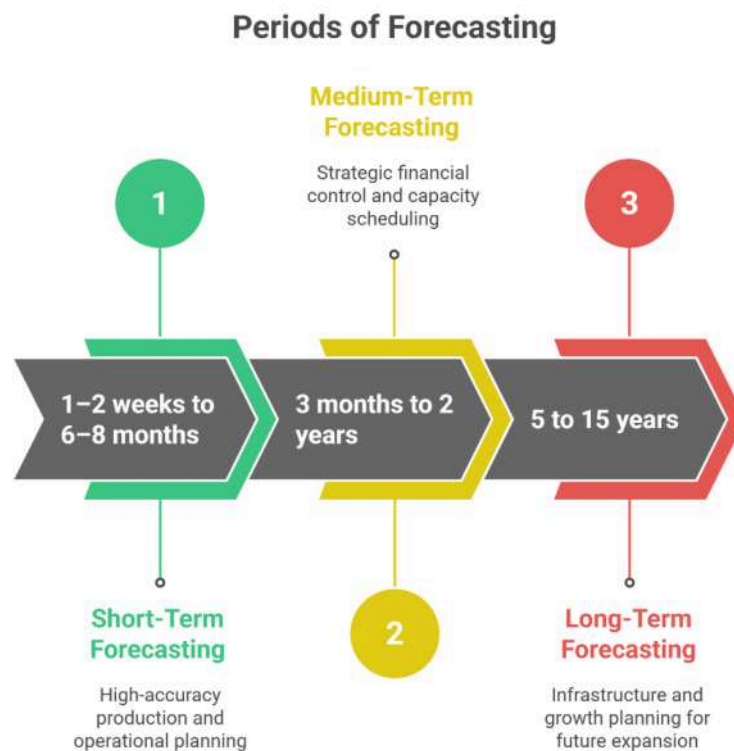
Sources of Information for Forecasting Demand

1.	Market Reports Provide trends and insights from the market.
2.	Sales Team Opinions Feedback from those who interact directly with customers.
3.	Expert Advice Views from specialists in the field.



4.	Industry Reports Data covering the overall industry.
5.	Point-of-Sale Data Real-time sales information from stores.
6.	Customer Surveys Direct input from buyers about preferences and needs.
7.	Field Reports Observations from on-ground staff in operational areas.

Range of Forecasting Periods



Made with Napkin

Type	Time Frame	Main Objectives	Key Focus
● Short-Term Forecasting	1-2 weeks to 6-8 months	1. Estimate inventory requirements 2. Arrange transport facilities for dispatch 3. Decide workloads for men and machines 4. Calculate working capital needs 5. Set up production runs 6. Fix sales quotas 7. Plan overtime to meet delivery deadlines	High accuracy for production planning
● Medium-Term Forecasting	3 months to 2 years	1. Control budgetary expenses 2. Decide dividend policies	Strategic planning and



		3. Manage and control maintenance costs 4. Schedule operations 5. Plan for capacity adjustments	financial control
● Long-Term Forecasting	5 to 15 years	1. Plan capital expenditure for new facilities 2. Forecast cash flow from future sales 3. Estimate manpower requirements 4. Plan for material needs 5. Guide R&D efforts	Long-term growth and infrastructure planning

📌 Summary Table - Range of Forecasting Periods

Forecast Type	Time Frame	Key Objectives
Short-Term	1 week to 6-8 months	Inventory, transport, workload, capital, production, sales quota, overtime
Medium-Term	3 months to 2 years	Budget control, dividends, maintenance, operations, capacity planning
Long-Term	5 to 15 years	Capital investment, cash flow, manpower, materials, R&D

■ A. Qualitative Forecasting Methods

Method Type	Basis	When Useful
Qualitative Methods	Rely on judgment, experience, and intuition rather than numerical data.	• When historical data is unavailable • For new product introductions • When market behavior is uncertain

Qualitative methods of Demand Forecasting



Method	Description	Key Points / When Useful
1. Survey of Buyer's Intentions (User Expectation Method)	Directly contacts actual users to ask about future buying intentions , usually for the upcoming year.	✓ Based on actual user info → more accurate ✓ Provides market & customer mindset insight ✓ Useful for new products ✓ Best for short-run forecasting
2. Collective Opinion (Sales Force Composite Method)	Gathers views from salesmen, branch managers, area managers, and sales managers ; consolidated by executives.	✓ Salespeople are close to customers, offering practical insights ✓ Adjusted for product changes, advertising, pricing, competition
3. Group Executive Judgement Method	Opinions from top executives across departments (marketing, finance, production) are combined to form a forecast.	✓ Involves cross-functional expertise ✓ Useful for strategic decisions and long-term planning
4. Experts' Opinions	Insights from external specialists like trade analysts, wholesalers, distributors, and agencies.	✓ Brings outside perspective ✓ Opinions analyzed to deduce sales forecasts
5. Market Test Method	Introduces product in a limited market area for a short period to estimate full-market demand.	✓ Suitable for new products ✓ Useful when purchase plans or data are unavailable ✓ Forecasts based on actual test sales performance

 Summary Table - Qualitative Forecasting Methods

Method	Key Feature	Purpose
1. Survey of Buyer's Intentions	Direct input from actual users	Accurate short-term forecasts, new product planning
2. Collective Opinion (Sales Force)	Sales team estimates consolidated	Territory-based forecasting, adjusted by executive review
3. Group Executive Judgement	Opinions from top executives	Strategic planning, cross-departmental insights
4. Experts' Opinions	External specialist insights	Industry-wide forecasting, external validation
5. Market Test Method	Trial sales in limited market	Estimating demand for new or uncertain products



Mnemonics for Qualitative Forecasting

Mnemonic: SCEGM ("Sce-gem")

Letter	Method
S	Survey of Buyer's Intention
C	Collective Opinion
E	Expert's Opinion
G	Group Executive Judgment
M	Market Test

Types of Forecasting Approaches

1.	Qualitative Based on judgment and opinion, e.g., Expert Opinion (Delphi method)
2.	Quantitative Based on numerical data; uses Causal / Regression Analysis

Regression Analysis

Regression Equations:

1. Regression of Y on X:

$$y = a + bx$$

2. Regression of X on Y:

$$x = \frac{y - a}{b}$$

Normal Equations (Method of Least Squares):

$$\begin{aligned} \sum y &= na + b \sum x \\ \sum xy &= a \sum x + b \sum x^2 \end{aligned}$$

Direct and Indirect Methods:

Method	Use	Formulas
Indirect	For non-time series data	$\begin{aligned} \sum y &= na + b \sum x, \\ \sum xy &= a \sum x + b \sum x^2 \end{aligned}$
Direct	For time series data	$\begin{aligned} a &= \frac{\sum y}{n}, \\ b &= \frac{\sum xy}{\sum x^2} \end{aligned}$
	Alternative Formulas (Easy Way):	$\begin{aligned} b &= \frac{n \sum xy - (\sum x)(\sum y)}{n \sum x^2 - (\sum x)^2} \\ a &= \bar{Y} - b\bar{X} \end{aligned}$ Where: - a = Y-axis intercept of regression line - b = slope of regression line - X = independent variable - Y = forecast value of dependent variable



- $\bar{X}, \bar{Y}$ = mean of respective variables
- n = number of data points

Quantitative Forecasting - Time Series Analysis

- Time Series Analysis**
A method to forecast future demand by analyzing historical data collected at regular intervals (hourly, daily, weekly, monthly).
- Purpose**
Helps identify patterns and trends in past data to make informed predictions for the future.

What Is Time Series Data?

Time series data tracks demand (Y) over time. This demand changes due to four key components:

Components of Time Series

Component	Meaning	Example
1. Trend (T)	Long-term movement in demand—either upward or downward	Increasing smartphone usage over years
2. Seasonality (S)	Regular, predictable changes based on time of year	Higher ice cream sales in summer
3. Cyclical (C)	Long-term fluctuations due to economic or business cycles	Demand drops during a recession
4. Irregular (I) or Random (R)	Unpredictable, short-term variations	Sudden spike due to viral marketing

Forecasting Models

Model	Formula	When Used
+ Additive Model	$Y = T + S + C + I$	When the impact of each component is independent and linear.
✗ Multiplicative Model	$Y = T \times S \times C \times I$	When components interact and amplify each other.

Key Highlights

- Data-Driven Method**
Time Series Analysis is quantitative and relies on historical data.
- Demand Prediction**
Helps businesses predict future demand more accurately.
- Operational Use**
Useful for inventory planning, budgeting, and capacity management.
- Model Selection**
Choice between Additive and Multiplicative models depends on the nature of the data.



Quantitative Forecasting Methods

Method	Description	Formula / Key Details	Best For
1. Forecasting by Forming a Trend Equation	Uses historical data to identify long-term upward or downward movements in demand.	Linear Trend: $F_t = a + bt$ F_t = Forecast for period t a = Y-intercept (forecast $t = 0$) b = Slope of trend line (rate of change) t = Number of time periods from start	Detecting consistent growth or decline over time
Types of Trends	Linear Trend - Most common and easiest Non-linear Trend - For curved or exponential growth	—	—
2. Forecasting by Averaging	Smooths short-term fluctuations to identify underlying patterns.	Simple Moving Average (SMA): Average demand over a fixed number of past periods	Stable demand with no strong seasonal or trend patterns

Weighted Moving Average (WMA)

Method	Description	Key Points / Formula	Best For
Weighted Moving Average (WMA)	Assigns different weights to past data points, giving more importance to recent observations .	Forecast = $\frac{\sum (\text{Weight} \times \text{Past Demand})}{\sum \text{Weights}}$	When recent trends are more relevant than older data

Summary Table - Forecasting Methods

Method	Purpose	Key Feature
1. Trend Equation	Long-term forecasting	Uses linear formula to project demand
2. Simple Moving Average	Short-term smoothing of demand	Equal weight to all periods
3. Weighted Moving Average	Emphasizes recent data	Higher weight to latest periods

Components of Time Series Data

Component	Definition	Key Features	Example	Key Insight
Trend (T)	Long-term upward or downward	Linear (steady) or Non-linear	Continuous rise in digital	Essential for long-

	movement in data over time	(accelerating/decelerating) • Driven by technology, consumer behavior, market evolution	payments over the past decade	term forecasting and strategic planning
Seasonality (S)	Short-term, regular and predictable variations due to seasonal patterns	• Repeats at fixed intervals (monthly, quarterly, yearly) • Caused by weather, holidays, cultural events	Increased demand for air conditioners in summer	Helps prepare for recurring demand shifts
Cycles (C)	Wave-like fluctuations lasting more than a year, often linked to economic/business cycles	• Irregular, not fixed like seasonality • Driven by inflation, recession, industry growth	Rise/fall in automobile sales based on economic conditions	Supports long-term strategic planning
Irregular / Random (I)	Unpredictable, erratic changes not explained by seasonality or cycles	• Caused by unexpected events (natural disasters, strikes, sudden market shifts) • Difficult to forecast	Sudden drop in travel bookings due to a pandemic	Reminds to build flexibility into forecasts

Summary Table - Components of Time Series Data

Component	Nature	Duration	Cause	Example
Trend (T)	Long-term movement	Years or decades	Market evolution, tech, behavior	Rise in digital payments
Seasonality (S)	Regular, short-term variation	Weeks to months	Seasonal factors (weather, holidays)	Air conditioner sales in summer
Cycles (C)	Long-term wave-like changes	Years	Economic/business cycles	Automobile sales fluctuations
Irregular (I)	Unpredictable, random changes	Sudden/short-lived	Unexpected events	Travel drop due to pandemic



2. Capacity Planning

Capacity in Operations Management

Concept	Definition / Description	Key Points / Examples
Capacity	The rate of output from an operating system per unit of time.	Measured in units per hour/day/week ; helps plan production, allocate resources, meet demand efficiently.
Production Capacity	Maximum rate at which a facility or firm can produce goods or services .	Example: A bakery producing 500 loaves/day .
Types of Capacity	—	—
1. Designed Capacity (Rated Capacity)	Maximum possible output under ideal conditions .	Usually higher than actual output; e.g., machine designed to produce 100 units/hour .
2. Planned Capacity (Effective Capacity)	Realistic output considering constraints (maintenance, breaks, downtime).	Always less than designed; e.g., effective output 80 units/hour due to maintenance.
3. Demonstrated Capacity (Actual Capacity)	Actual output achieved over time based on historical performance .	E.g., machine consistently producing 75 units/hour .

Summary Table - Types of Capacity

Type of Capacity	Definition	Key Feature
1. Designed Capacity	Maximum output under ideal conditions	Highest possible rate
2. Planned (Effective) Capacity	Realistic output considering limitations	Lower than designed capacity
3. Demonstrated (Actual) Capacity	Actual output achieved over time	Based on real performance

☑ Why Is Capacity Important?

1.	Resource Planning Helps plan and allocate resources efficiently.
2.	Timely Delivery Ensures products/services are delivered on time .
3.	Cost Control Supports monitoring and reducing costs .
4.	Scaling Operations Aids in expanding operations smoothly.



⚙ Utilization and Efficiency

KPI	Definition	Formula	Key Points	Example
Utilization	Measures how much of the design capacity is actually used.	$\text{Utilization} = \frac{\text{Actual Output}}{\text{Design Capacity}} \times 100\%$	- Design Capacity = maximum output under ideal conditions. - High utilization → system used efficiently. - Indicates need to increase or reduce capacity.	Design = 100 units/day, Output = 80 → Utilization = 80%
Efficiency	Measures how effectively the effective capacity is being used.	$\text{Efficiency} = \frac{\text{Actual Output}}{\text{Effective Capacity}} \times 100\%$	- Effective Capacity considers real-world limitations (maintenance, breaks, delays). - Focuses on performance under realistic constraints. - High efficiency → optimal use of resources.	Effective Capacity = 90 units/day, Output = 80 → Efficiency = 88.89%

🏭 Capacity Planning

1. **Capacity Planning**
A **strategic process** that determines the **right resources** to meet **future demand** efficiently.

🎯 Three Core Questions of Capacity Planning

Question	Focus / Explanation
What kind of capacity is needed?	Determines types of resources : machines, labor, storage, transport, etc.
How much capacity is needed?	Specifies quantity of resources required to meet demand.
When is this capacity needed?	Identifies timing for expansion or adjustment.
☑ Purpose	Guides long-term decisions to align supply capabilities with expected demand.



Purpose of Capacity Planning

1.	Aligns Resources Matches resource levels with future demand .
2.	Supports Growth Facilitates strategic expansion of operations.
3.	Prevents Imbalance Avoids underutilization or overload of resources.

Reasons for Capacity Planning

1.	Meet Customer Demand Ensures products/services are delivered on time .
2.	Improve Cost Efficiency Helps reduce waste and control expenses .
3.	Optimize Scheduling Enhances planning and workflow efficiency .
4.	Major Investment Consideration Capacity creation requires significant resources .
5.	Guide Strategic Decisions Supports choices on facility location and process technology .

Types of Capacity Planning

Type	Focus Area	Time Frame
Long-Term	New facilities, major equipment	More than 2 years
Short-Term	Workforce size, overtime, inventory adjustments	Weeks to months

Key Activities in Capacity Planning

1.	Assess Current Capacity Evaluate existing facilities and resources .
2.	Forecast Future Demand Predict long-term demand for products/services.
3.	Identify Capacity Sources Determine options like new equipment or outsourcing .
4.	Evaluate Alternatives Consider financial feasibility , technological readiness , and economic impact .
5.	Select Best Option Choose the solution that aligns with strategic goals .

Factors Influencing Capacity Expansion

1.	Competitive Pressure Ensures organization stays ahead in the market .
2.	Market Opportunities



	Enables response to growth or new market segments .
3.	Costs & Funds Availability Balances investment with budget constraints .
4.	Disruption of Operations Minimizes downtime during expansion or changes.
5.	Training Requirements Prepares workforce for new systems and processes.

⚠ Possible Capacity Situations

Situation	Description	Impact
Excess Capacity	Capacity exceeds forecasted demand	Leads to waste and higher costs
Capacity Shortage	Capacity is insufficient to meet future demand	Causes delays and lost sales

Decision	Definition	Preferred When	Risks	Example
Overcapacity	Firm has more production capability than current demand.	• Low fixed costs - extra capacity inexpensive • Subcontracting not viable • Capacity expansion takes time • Critical delivery deadlines • Minimum efficient scale	• Drains financial resources • Limits investment in profitable areas	Luxury car manufacturer maintains extra lines to ensure quality and timely delivery .
Undercapacity	Firm has less production capability than potential demand.	• High fixed costs - avoids heavy investment • Recoverable lost sales • Rapid tech evolution • Costly capacity expansion	• Loss of customers • Slows business growth	Tech startup stays lean to avoid investing in soon-to-be-obsolete equipment .

📊 Comparison Table - Overcapacity vs. Undercapacity

Aspect	Overcapacity	Undercapacity
Fixed Cost	Low	High
Subcontracting Option	Not feasible	Feasible
Expansion Time	Long	Flexible
Customer Sensitivity	High - delays not acceptable	Low - lost sales recoverable
Technology Stability	Stable	Rapidly changing

Investment Risk	May drain resources	Avoids premature investment
Impact on Growth	Ensures readiness	May slow down growth

	🎯 Key Takeaway
1.	Cost Structure Determines if overcapacity or undercapacity is more financially viable.
2.	Market Expectations Guides capacity based on demand trends and customer expectations .
3.	Technology Dynamics Considers tech changes and equipment obsolescence.
4.	Strategic Priorities Aligns capacity with long-term business goals .
5.	☒ Goal Balance risk, cost, and customer satisfaction to support sustainable success .

3. Facility Location and Layout

Explanation / Examples	
1.	Fundamental Questions 1. What to produce? 2. How much to produce? 3. Where to produce? → Leads to Facility Location & Layout
2.	Facility Any physical setup needed to operate, produce goods, or deliver services. Examples: factories, warehouses, service centers, offices
3.	Location The geographical place where a facility is established. Examples: industrial zones, urban centers, near ports/highways
4.	Facility Location Decision Core Question: Where should the setup be established to optimize performance and cost?
5.	Need for Appropriate Location Critical when launching a new business, expanding markets, resource shortages, lease expiration/relocation, or navigating socio-cultural, legal, political, or economic challenges
6.	☒ Goal A well-chosen location ensures long-term sustainability and growth.

Content	
1.	Cost Savings Lower fixed costs (rent, utilities), reduced variable costs (labor, materials), and minimized transportation costs.
2.	Proximity to Markets & Resources Enables faster delivery, easier access to raw materials, and improved customer service.
3.	Efficient Transportation Supports smooth logistics and reliable supply chain operations.

🧠 Strategic Summary	
1.	Reduce Operational Costs Helps lower expenses related to production, labor, and logistics.
2.	Maximize Service Quality Supports efficient operations and customer satisfaction.
3.	Maintain Visibility & Access Ensures easy access to customers and suppliers.
4.	☒ Strategic Impact Directly influences competitiveness, profitability, and long-term success.



	Facility Location Selection - Key Factors Explained
1.	Strategic Importance Choosing the right factory, office, or warehouse location impacts costs, delivery speed, and growth potential .
2.	Decision Factors Companies consider key factors to ensure the location supports efficiency, competitiveness, and long-term success .

Factor	Meaning	Example
Sourcing	Easy access to raw materials, energy, water, and suppliers ; good transport and logistics.	Car manufacturer near steel suppliers to reduce transport costs and ensure steady supply.
Markets	Close to customers for faster delivery and wider coverage.	E-commerce warehouse near a city for same-day delivery.
Cost	Includes rent, transport, taxes , and hidden costs like utilities.	Tech startup chooses a city with lower rent to reduce overhead.
Socio-cultural & Political	Safe, friendly community; good laws; quality of life for employees.	Multinational sets up in a city with good schools and hospitals to attract skilled workers.
Environmental Concerns	Clean air and water , proper waste disposal, supports sustainability .	Renewable energy company chooses a sunny/windy location for efficiency.
Skilled Labor	Availability of trained workers and proximity to universities/training centers.	Software company opens near a tech hub for graduates and experienced developers.
Competitive Pressure	Location with fewer competitors or where the company has an advantage.	Retail chain opens in a town with no similar stores to capture the market.
Operational Efficiency	Space to grow, good transport access , low running costs, cooperative labor force.	Manufacturing plant chooses a site with room to expand and smooth logistics.
Sustainability	Supports environmental goals ; good air, water, and land quality.	Company sets up in a clean, green area to meet eco-friendly targets.
Technological Connectivity	Fast internet , strong digital infrastructure, readiness for tech-based operations.	Tech firm selects a city with high-speed internet and modern IT facilities.
Strategic Benefits	Better logistics, centralized control , easier coordination, supports future growth.	Company chooses a central location to manage supply chains and expand easily.

	 Main Factors to Consider
1.	Sourcing Easy access to raw materials, energy, water, and suppliers. Good transport links.
2.	Markets Close to customers for fast delivery and wide market coverage.
3.	Cost Affordable rent, transport, taxes, and hidden expenses.
4.	Socio-cultural & Political Supportive community, safe area, good laws, and quality of life.
5.	Environmental Concerns Clean air and water, proper waste disposal, and eco-friendly surroundings.
6.	Skilled Labor Availability of trained workers and nearby educational institutions.
7.	Competitive Pressure Fewer competitors or better access to resources and customers.
8.	Operational Efficiency Space to grow, good transport, low running costs, and friendly labor conditions.
9.	Sustainability Environmentally safe location that supports green goals.
10.	Technological Connectivity Fast internet, digital infrastructure, and tech readiness.
11.	Strategic Benefits Better logistics, centralized control, and future growth opportunities.

 Easy Mnemonic: SMART COSTS

Letter	Factor	Meaning / Focus
S	Sourcing	Access to raw materials, energy, water, suppliers , and good logistics.
M	Markets	Proximity to customers for faster delivery and wider coverage.
A	Availability of Skilled Labor	Access to trained workers and educational/training centers.
R	Regulatory & Socio-cultural	Friendly community, safe environment, good laws, and quality of life.
T	Transportation & Cost	Efficient logistics , low running costs, and cost-effectiveness.
C	Competitive Pressure	Location with fewer competitors or strategic advantage.
O	Operational Efficiency	Space to grow, smooth operations, cooperative workforce.
S	Sustainability	Supports environmental goals , clean air/water/land.
T	Technological Connectivity	Fast internet , strong digital infrastructure, tech-readiness.



S	Strategic Benefits	Centralized control, better logistics, easier coordination, supports growth.

Popular Methods for Facility Location Selection

Method	What It Does	How It Works / Steps	Why Use It
Factor Rating Method	Evaluates locations based on key factors (cost, labor, transport, environment).	- List factors - Assign weights - Score locations - Multiply scores by weights - Select highest total	Simple, flexible, and supports balanced decisions .
Centre of Gravity Technique	Finds central location to minimize transportation costs .	- Plot demand points - Use coordinates & shipment volumes - Select nearest point	Ideal for distribution centers and multi-region warehouses.
Transportation Model	Optimizes transportation and distribution costs using mathematical techniques .	- Define supply & demand - Calculate transport costs - Use linear programming for lowest-cost solution	Best for complex supply chains with multiple facilities.
Optimization & Heuristic Models	Uses advanced mathematical and problem-solving models for best location.	Optimization Models: formulas for ideal solution Heuristic Models: rules/shortcuts for good solution quickly	Useful for large-scale decisions with many factors and locations.

Summary Table - Facility Location Methods

Method	Purpose	Best For
Factor Rating Method	Compare locations using weighted scores	General location decisions
Center of Gravity Technique	Minimize transport cost by finding midpoint	Warehouses, distribution centers
Transportation Model	Optimize shipping cost across locations	Complex supply chains
Optimization/Heuristic Models	Find best or near-best location using math	Large-scale, multi-variable decisions

■ Concept Note: Facility Layout

	 What is Facility Layout?
1.	Facility Layout / Plant Layout Arrangement of departments, work centers, machines, and equipment within a facility to ensure smooth flow of materials and people.
2.	☒ Goal Maximize efficiency and productivity by organizing space and movement effectively.

	 Key Concepts												
1.	Definition Physical arrangement of machines, workstations, storage areas, offices, and more inside a plant or building.												
2.	Purpose Ensure smooth flow of materials, people, and information; reduce waste, travel time, and delays.												
3.	Elements Included <table border="1"> <thead> <tr> <th>Area Type</th><th>Examples</th></tr> </thead> <tbody> <tr> <td> Production Areas</td><td>Machines, equipment, workstations</td></tr> <tr> <td> Storage Areas</td><td>Raw materials, finished goods, tool cribs </td></tr> <tr> <td>Support Areas</td><td>Offices, computer rooms, customer service</td></tr> <tr> <td> Utility & Comfort Zones</td><td>Restrooms, lunch rooms, coffee/tea bays</td></tr> <tr> <td> Movement Paths</td><td>Aisles, corridors, flow patterns</td></tr> </tbody> </table>	Area Type	Examples	 Production Areas	Machines, equipment, workstations	 Storage Areas	Raw materials, finished goods, tool cribs 	Support Areas	Offices, computer rooms, customer service	 Utility & Comfort Zones	Restrooms, lunch rooms, coffee/tea bays	 Movement Paths	Aisles, corridors, flow patterns
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 Movement Paths	Aisles, corridors, flow patterns												

	 Economic Activity Centers
1.	Economic Activity Center Any space-consuming entity in a facility.
2.	Examples • Person or team • Machine or workstation • Department or storage room
3.	☒ Placement Goal Must be placed strategically to minimize movement and maximize output.

	 Objectives of Layout Planning
1.	Improve Workflow & Communication Ensures smooth operations and effective team interaction.
2.	Enhance Safety & Comfort Creates a safe and comfortable working environment.
3.	Optimize Space Utilization

	Makes the most of available space efficiently.
4.	Reduce Operational Costs Minimizes expenses related to production and movement.
5.	Support Future Expansion Facilitates growth and scalability of the facility.

	⚡ Why It Matters
1.	Boosts Employee Productivity Enhances efficiency and performance of employees.
2.	Improves Customer Experience Supports better service and satisfaction.
3.	Enables Scalability & Flexibility Allows growth and adaptation to changing needs.
4.	Reduces Errors & Downtime Minimizes mistakes and production interruptions .

Types of Layout:

1.	Process Layout ➤ Also called functional layout or job shop layout. Machines are grouped based on similar processes.
2.	Product Layout ➤ Also called line processing layout or flow-line layout. Machines are arranged in the sequence of production.
3.	Fixed Position Layout ➤ Also called static layout. The product remains stationary, and materials and workers are brought to it.
4.	Cellular Manufacturing (CM) ➤ Also called Group Technology layout. Machines are grouped into cells to handle similar products or processes.
5.	Combination Layout ➤ Also called Hybrid layout. A mix of different layout types to optimize production.

Process Layout:

Layout Type	Also Called	Concept
Process Layout 	Functional Layout, Job Lot Manufacture Layout, Batch Production Layout	Groups similar machines or equipment into departments based on their function or operation type .

	🔑 Key Characteristics
1.	Grouping by Function Machines with similar operations are grouped together.

2.	Example Departments • Drilling → Drill presses, boring machines • Turning → Centre lathes, turret lathes • Machining → Milling machines, grinders • Painting → Spray booths, drying ovens • Electroplating → Plating tanks, rinsing stations
3.	Operational Flow Material moves between departments based on process requirements; flexible routing , not straight-line.

	⚙️ Advantages of Process Layout
1.	High Flexibility Handles varied products efficiently.
2.	Better Equipment Utilization Maximizes use of specialized machines .
3.	Easier Supervision & Maintenance Simplifies management and upkeep within departments.
4.	Ideal for Custom & Low-Volume Production Suited for custom orders and small batch production .

	⚠️ Limitations
1.	Longer Material Handling Time Material moves between departments , increasing transport time.
2.	Complex Routing & Scheduling Flexible flow makes planning and coordination more difficult.
3.	Higher Work-in-Progress Inventory More in-process inventory accumulates between departments.
4.	Requires Skilled Labour Needs trained workers for handling diverse operations.

	Content
1.	Job Shops Facilities handling custom or small-batch orders .
2.	Custom Manufacturing Produces tailor-made products to meet specific customer needs.
3.	Repair Workshops Handles maintenance and repair tasks efficiently.
4.	High Variety, Low Volume Industries Industries with diverse products produced in small quantities .

	🔗 Real-World Examples
1.	Automobile Repair Centres Separate zones for engine work, painting, electrical repairs.
2.	Metal Fabrication Shops Dedicated departments for cutting, welding, grinding.
3.	University Labs Specialized labs: Physics, Chemistry, Electronics with appropriate equipment.

📊 Concept Note: Product Layout

Layout Type	Also Called	Concept / Flow
Product Layout 🏭	Straight-Line Layout, Layout for Serialised Manufacture	Machines are arranged in one line based on sequence of operations. Flow: Material enters first machine → moves through intermediate machines → finished product exits last machine.

🔗 Real-World Examples

Industry	Input → Output Flow
🏭 Sugar Mill	Sugarcane → Sugar
📄 Paper Mill	Bamboo → Paper
🚗 Car Plant	Raw parts → Assembled vehicle
🍫 Chocolate Factory	Cocoa → Packaged chocolate bars

Example	Explanation / Flow
Sugar Mill	Sugar cane fed at one end, processed through machines, sugar comes out at the other end.
Paper Mill	Bamboo fed at one end, processed through machines, paper comes out at the other end.

	Investment Consideration
1.	Higher Investment Required Product layout uses special-purpose machines, demanding more capital than functional layouts.
2.	Comparison to Functional Layout Straight-line layout requires higher machine investment than functional layout.

	🔗 Advantages of Product Layout
1.	High Production Efficiency Optimizes output by arranging machines sequentially.
2.	Smooth Material Flow Ensures continuous movement from one operation to the next.
3.	Reduced Handling Time

	Minimizes material movement and delays.
4.	Ideal for Mass Production Suited for large-scale, standardized products.

	⚠ Limitations
1.	Low Flexibility Difficult to accommodate product changes or variations.
2.	High Initial Investment Requires more capital for special-purpose machines.
3.	Vulnerability to Breakdown Failure of one machine can halt the entire production line.

	Fixed Position Layout / Static Layout
1.	Concept Product remains stationary; workers, tools, machinery, and materials are brought to it.
2.	Best Suited For - Bulky, heavy, or immobile products - Projects needing custom assembly at a specific location
3.	Key Characteristics - Stationary Product: Major component stays in one place; all resources come to it. - Cost Efficiency: Moving men/machines is cheaper than moving large product; reduces transportation cost and handling effort.
	Application Ideal for massive equipment, ships, airplanes, or construction projects.

🔗 Real-World Examples

Industry	Product Manufactured
🚢 Shipbuilding	Ships
🚂 Locomotive Plants	Locomotives
🔥 Boiler Manufacturing	Industrial Boilers
✈ Aerospace	Aircrafts
⚡ Power Equipment	Generators

"This type is followed in the manufacture, if bulky and heavy products, such as locomotives, ships, boilers, air crafts and generators."

	Fixed Position Layout / Mixed Layout
1.	Fixed Position Layout - Benefits - Ideal for large-scale, custom-built products - Reduces material handling costs - Allows flexible scheduling and on-site adjustments - Enhances worker specialization at the product site
2.	Fixed Position Layout - Limitations

	- Requires high coordination among teams - May cause congestion at the work site - Difficult to manage inventory and tools efficiently
3.	Mixed / Combined Layout - Concept Blends Product Layout and Process Layout principles; commonly used when products are somewhat similar and not complex
4.	Key Highlights Combination of layouts depending on production needs - Offers flexibility and efficiency - Most plants use hybrid approach rather than pure layouts - Efficient for products with common features
5.	Best Suited For - Industries with moderate product variety Semi-standardized production - Plants aiming for flexibility with efficiency

Examples

Industry	Mixed Layout Application
 Garment Manufacturing	Cutting (process layout) + Stitching line (product layout)
 Electronics Assembly	Component prep (process) + Assembly line (product)
 Auto Parts Production	Machining (process) + Final assembly (product)

	Content
1.	Mixed / Combined Layout - Advantages - Combines flexibility of process layout with efficiency of product layout - Adapts to changing production needs - Reduces idle time and material movement - Supports scalable operations
2.	Mixed / Combined Layout - Limitations - Requires careful planning - May involve higher initial setup cost - Needs skilled management to balance both systems
3.	Service Facility Layout - Concept Connects customers with services efficiently and comfortably , unlike manufacturing layouts that focus on production flow.
4.	Key Features Easy Access: Convenient entry points, clear signage, traffic-friendly design Parking & Walkways: Spacious, well-lit parking and safe, accessible walkways
5.	Customer-Centric Layout - Designed around customer experience and interaction - Example: Banks - counters, waiting areas, ATMs, consultation rooms
6.	Technology-Centric Layout

- Focuses on **technical operations**, workflow, and equipment efficiency
- Example: **Hospitals** - operating rooms, labs, patient wards, diagnostic centers

4. Resource Aggregate Planning

■ Concept Note: Aggregate Planning

1.	Definition Intermediate-term planning of quantity and timing of output over a moderate horizon (3 months-1 year).
2.	Time Frame Intermediate range , between short-term and long-term; usually 3 months to 1 year .
3.	Fixed Facilities Buildings and equipment assumed fixed; adjustments made via labor and inventory schedules .
4.	Objective Find best combination to minimise costs , match demand fluctuations , and achieve cost efficiency without changing infrastructure.
5.	Why "Aggregate"? Planning is done in total units , not detailed product mix. Example: aggregate number of vehicles, aggregate number of soaps.

⊗ Types of Planning in Production

Planning Type	Time Horizon	Focus Area
🧠 Long-Range	1-5 years	Strategic decisions (new products, facilities)
⚙️ Short-Term	Daily to weekly	Scheduling, inventory, operations
📊 Intermediate (Aggregate)	3 months-1 year	Balancing demand and capacity economically

Industry	Aggregate Planning Example
🚗 Automobile	Plan for 10,000 vehicles over 6 months
🧼 FMCG (Soaps)	Produce 500,000 units over the next quarter
🏭 Manufacturing	Balance seasonal demand with available workforce

Aspect	Explanation / Features
1.	Benefits of Aggregate Planning • Aligns production with demand • Controls costs and resource usage • Supports efficient scheduling • Bridges strategic and operational planning
2.	Mnemonic - W-H-I-S • W - Workforce size • H - Hours worked • I - Inventory levels



	• S - Subcontracting
3.	Pure Strategy 1 - Vary Workforce Size Hire or lay off workers to match demand fluctuations . Example: Toy factory hires seasonal workers before Christmas.
4.	Pure Strategy 2 - Vary Hours Worked Maintain stable workforce , use idle time in slack periods, overtime in peak periods. Example: Bakery runs extra shifts during festival season.
5.	Pure Strategy 3 - Vary Inventory Levels Build inventory in advance to meet sudden demand. Example: Soap manufacturer stocks up before a promotional campaign.
6.	Pure Strategy 4 - Subcontract Use external vendors to meet increased demand, avoiding overloading internal capacity. Example: Car company outsources seat manufacturing during peak orders.

Summary Table

Strategy	Description	Example
Vary Workforce Size	Hire/lay off based on demand	Seasonal hiring in retail
Vary Hours Worked	Use idle time or overtime with stable workforce	Extra shifts in food production
Vary Inventory	Build inventory to meet future demand	Stockpiling soaps before launch
Subcontracting	Use external vendors to meet excess demand	Outsourcing parts in auto sector

Why These Strategies Matter

1.	Balance Demand & Capacity Ensures production meets demand without overloading resources.
2.	Minimize Costs & Disruptions Reduces expenses and operational interruptions .
3.	Improve Flexibility & Responsiveness Enhances ability to adapt to demand fluctuations.
4.	Support Efficient Operations Planning Facilitates smooth scheduling and resource allocation .

5. Material Requirements Planning

■ Concept Note: Materials Requirement Planning (MRP)

📅 What is MRP?

1.	Materials Requirement Planning (MRP) Technique to determine quantity and timing of dependent demand items to meet master production schedule .
2.	Purpose Helps manufacturers decide what materials are needed, how much , and when .
3.	Key Benefit Powerful tool for effective manufacturing control .

🧠 Mnemonic to Remember MRP Objectives:

IRRI Component	Explanation / Features	Example
I - Inventory Reduction	Determines what materials are needed and when , avoiding excess inventory; procure just in time .	Mobile phone company orders screens only when assembly is scheduled.
R - Reduction in Lead Time	Identifies quantities and timings , ensuring materials are available to prevent delays.	Furniture factory schedules wood delivery exactly when cutting begins.
R - Realistic Delivery Commitments	Provides accurate delivery times to marketing and customers, building trust.	Electronics brand promises laptop delivery in 5 days based on MRP data.
I - Increased Efficiency	Coordinates work centres and material flow for smooth operations.	Car plant ensures tires, engines, and seats arrive at the right time for assembly.

6. Manufacturing Resource Planning

■ Concept Note: Manufacturing Resource Planning (MRP II)

1.	MRP II - Manufacturing Resource Planning Comprehensive tool for planning and controlling the manufacturing process and all related support functions.
2.	Scope Extends beyond materials to include capacity, finance, engineering, sales, and marketing.
3.	Purpose Helps managers achieve integrated, efficient operations across the entire manufacturing system.

Content

1.	Holistic Planning Covers materials, capacity, finance, engineering, sales, and marketing; integrates all major manufacturing functions.
2.	Universal Applicability Suitable for any manufacturing organization, regardless of size, location, product, or process; works across industries and geographies.
3.	How MRP II Works Converts business plans into actionable tasks, ensuring coordination and accountability across departments.

🏢 Departmental Roles in MRP II

1.	📦 Materials Maintain inventory and supply schedules
2.	⚙️ Engineering Keep Bill of Materials (BOM) updated
3.	📊 Sales/Marketing Maintain accurate sales plans
4.	🛒 Purchasing Ensure timely procurement of bought-out items
5.	🏭 Manufacturing Meet production deadlines for in-house manufactured items

"It involves all departments... that must maintain bill of materials, keep sales plan up to date, and meet due dates..."

Explanation / Features

1.	Real-World Example Bicycle manufacturer: - Sales forecasts 10,000 bikes - Engineering updates BOMs

- Materials team ensures **tires, chains, frames** are available
- Purchasing orders **outsourced components** like gears
- Manufacturing schedules **assembly** to meet delivery dates

MRP II aligns all departments with the business plan

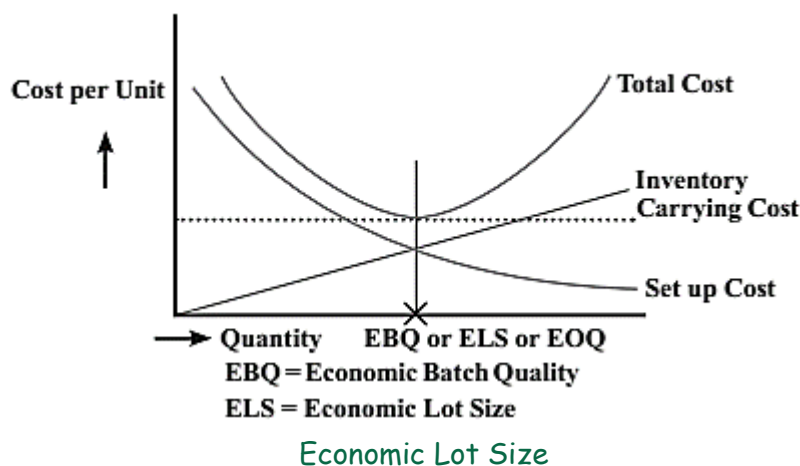
2. **Benefits of MRP II**

- Improves **cross-department coordination**
- Enhances **planning accuracy**
- Supports **realistic scheduling**
- Boosts **accountability and efficiency**
- Enables **data-driven decision making**



7. Economic Batch Quantity

	Concept
1.	Economic Lot Size ➤ 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).
2.	Factors Affecting Economic Lot Size 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).
3.	Capacity Verification ➤ Before choosing an economic lot size, ensure production capacity is available to produce the required batch size.
4.	Balancing Costs ➤ The economic lot size balances two opposing costs: 1. Setup Costs: Decreases with larger lot sizes. 2. Inventory Carrying Costs: Increases with larger lot sizes.
5.	Key Concept ➤ A larger lot size results in lower setup costs per unit but higher inventory carrying costs.



Concept	Formula	Variables / Explanation
Economic Batch Quantity (EBQ)	$EBQ = \sqrt{\frac{2AS}{C}}$	• A = Annual demand (units) • S = Setup cost per setup (Ordering cost)

		• C = Production cost per unit × Inventory carrying charges (%)
Purpose	Determines optimal batch size to minimize total production and inventory costs.	Produces items efficiently while balancing setup costs and holding costs .
Economic Run Length (ERL)	$ERL = \sqrt{\frac{2AS}{C_1 \left(1 - \frac{d}{p}\right)}}$	• A = Annual demand (units) • S = Setup cost per setup • C_1 = Production cost per unit × Inventory carrying charges (%) • d = Demand rate (consumption rate) • p = Production rate
Purpose	Calculates optimal production run when items are made for inventory rather than bought.	Adjusts for difference between production rate and demand rate to avoid shortages or excess inventory.

MODULE 3. DESIGNING OF OPERATIONAL SYSTEM AND CONTROL

1. Product Design

	■ Concept Note: Product Design
1.	Role of Product in the Marketing Mix The product is a key part of the marketing mix . Customers pay for products that best meet their needs and deliver value . The features and quality of a product drive demand , which creates value chains and supports organizations .
2.	Strategic Importance of Product Design Product design is a strategic decision . It involves structured and interdependent activities planned to create value propositions that satisfy customer needs .
3.	Basic Objectives of Product Design • Create products that match customer needs and provide optimum value • Reduce costs and time-to-market (design to market) • Improve resource utilization
4.	Importance of Product Design Product design strongly influences a company's success . It is more than just aesthetics —it defines how a product meets needs and stands out in the market .

	Content
1.	Key Objectives of Product Design • Define core and augmented characteristics to match market demand and competition • Specify technical requirements and process needs • Provide guidelines for production system design • Support production and operations strategy
2.	Strategic Impact A strong product design helps organizations: • Stay ahead of competition • Survive in a VUCA world (Volatile, Uncertain, Complex, Ambiguous) • Build long-term customer relationships • Influence employment indirectly• Act as an order-winning factor

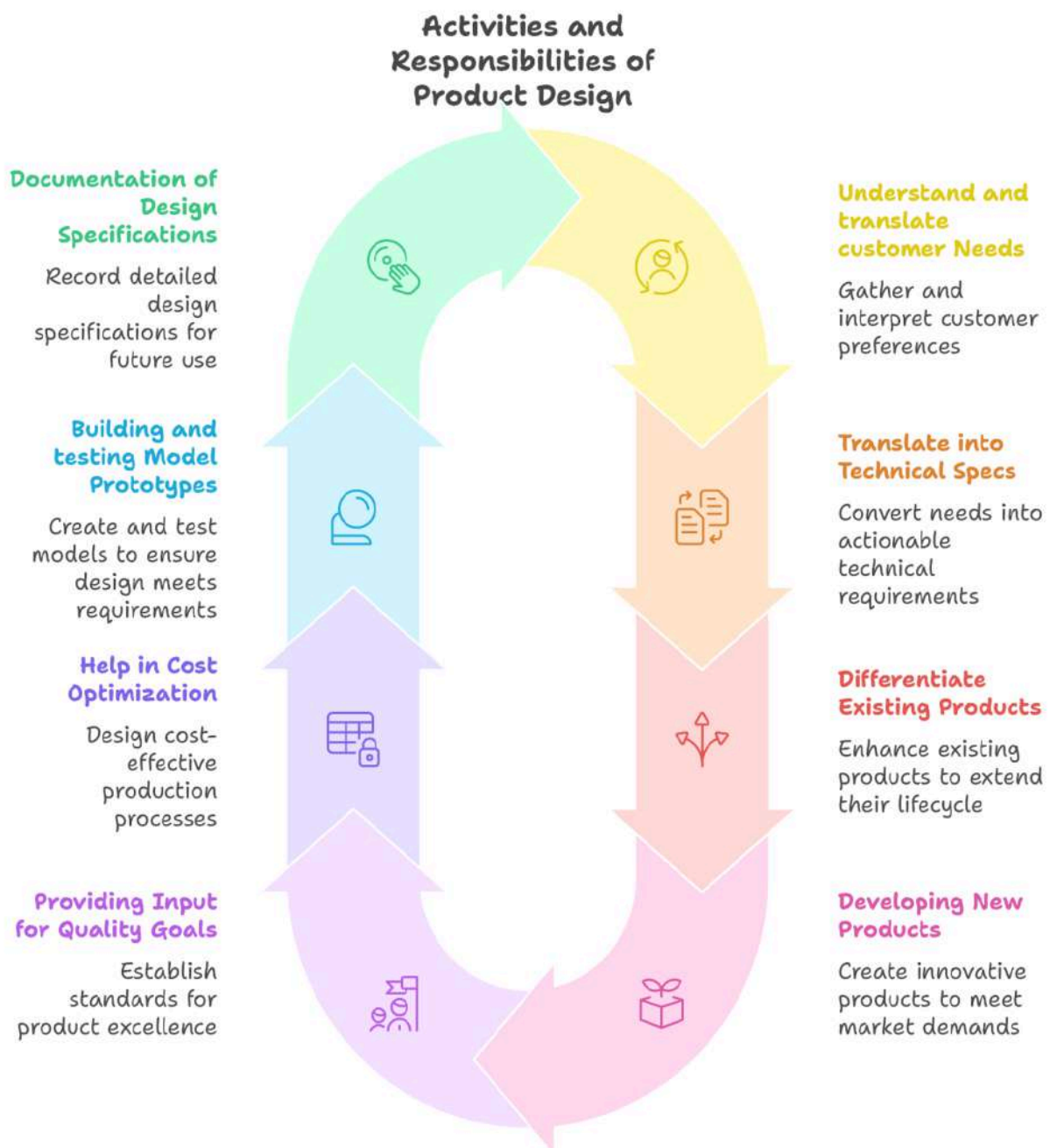
✦ Attributes of a Good Product Design

Attribute	Description
👤 User-Friendliness	Easy and intuitive to use
😊 Aesthetics	Visually appealing
⚙️ Features	Functional and relevant
🛡️ Reliability	Consistent performance

 Durability	Long-lasting and robust
 Innovativeness	Fresh, creative, and unique
 Appropriateness	Suitable for intended use and context

	Simplified Explanation
1.	Concept Note: What Does Product Design Do? Product design translates customer needs into market-ready solutions. It ensures products are valuable, competitive, and aligned with organizational goals.

Activities and Responsibilities of Product Design



#	Activity / Responsibility	Simplified Description	Example
1	Understanding Customer Needs	Translate customer requirements (Voice of the Customer) into technical requirements (Voice of the Process) for design and planning.	Smartphone company converts requests for better battery life into specs like 5000mAh battery + power-efficient chipset .
2	Product Differentiation	Add new features to existing products to extend the product life cycle .	Car maker adds sunroof + infotainment upgrades to refresh an existing model.
3	New Product Development	Create entirely new products to meet evolving customer needs.	Wearable tech firm introduces a fitness tracker with hydration monitoring .
4	Input for Quality Goals	Provide benchmarks that guide quality standards.	Design team sets targets for resolution, durability, and performance .
5	Cost Optimization	Help reduce production costs without lowering quality.	Replace metal casing with high-grade polymer to save costs.
6	Prototype Development & Testing	Build and test model prototypes before full production.	Furniture brand uses a 3D-printed chair prototype to check ergonomics.
7	Design Documentation	Create detailed design specs for manufacturing.	Engineers prepare CAD drawings and material lists for production.

🧠 Mnemonic: "3D-QCTP"

Use **3D-QCTP** to remember the key responsibilities of product design:

Letter	Stands For
D	Differentiate existing products
D	Develop new products
D	Document design specifications
Q	Quality goals formulation
C	Cost optimization
T	Translate customer needs into technical requirements
P	Prototype building and testing

	Summary
1.	Role of Product Design Product design is the strategic engine that drives innovation, customer satisfaction, and operational efficiency.



2.	Core Purpose It makes sure products are desirable, feasible, and sustainable.

	Concept Note: Factors Affecting Product Design
1.	Influence on Product Design Product design is shaped by several factors that affect how well a product: • Meets customer expectations • Performs in the market • Aligns with organizational capabilities



Made with Napkin

#	Factor	Simplified Explanation	Example
1.	Customer Needs (Stated & Unstated)	Understanding both explicit and latent needs is crucial. Modern designers often use social media analytics to discover hidden preferences.	Fashion brand uses Instagram trends to spot new styles.
2.	User-Friendliness	Products must be easy to use and appeal across demographics .	Smartphone with simple interface suits both youth and elderly.
3.	Balance of Form, Function & Cost	Need a balance between design, features, and affordability (economies of scale vs. scope).	Budget car with stylish look, fuel efficiency, and low cost .
4.	Raw Material Quality	Good design depends on high-quality inputs .	Luxury chocolate brand uses premium cocoa .
5.	Process & Layout Design	Efficient production processes reduce errors and bottlenecks.	Electronics firm optimizes assembly line layout .
6.	Machines & Instruments	Quality of tools directly affects design accuracy.	Watchmakers rely on precision tools .
7.	Process Capability & Maturity	Mature processes improve efficiency and reduce errors .	3D printing enables rapid prototyping .
8.	Skilled Resources	Expertise of designers & engineers drives innovation.	Skilled team builds innovative, reliable products .
9.	Impact on Existing Products	New designs may affect the life cycle of older products.	New smartphone release leads to updates/discontinuation of older models.
10.	Product Presentation (Packaging)	Attractive or eco-friendly packaging boosts brand image.	Green packaging appeals to eco-conscious customers .

🧠 Mnemonic: "U-FORM Q-SCOPE"

Use **U-FORM Q-SCOPE** to remember the 10 key factors:

Letter	Stands For
U	Understanding customer needs
F	User-friendliness
O	Optimizing form, function, and cost
R	Raw material quality
M	Machine/instrument condition
Q	Quality of processes
S	Skilled resources
C	Consideration of existing products
O	Operational layout/design



P	Presentation (packaging)
E	Economies of scale & scope balance (embedded in point 3)

	✦ Final Insight
1.	✦ Nature of Product Design Product design is a multi-dimensional discipline.
2.	🔗 Outcome By managing the right factors, organizations can build products that are functional, cost-effective, and strongly connect with customers.

■ Concept Note: Characteristics of Good Product Design

Characteristics of Good Product Design



#	Requirement	Simplified Explanation	Example
(a)	Product Quality	Must meet customer needs and deliver optimum value with expected performance.	Water purifier that ensures clean, safe water.
(b)	Reliability	Product should be trustworthy and worth paying for.	Laptop that works well over time without breakdowns.
(c)	Optimum Cost	Designed at the right cost to remain affordable for target customers.	Budget smartphone for students with essential features.

(d)	Short Design-to-Market Time	Products should reach the market quickly.	Fashion brand releasing seasonal collections fast.
(e)	Aesthetics	Attractive looks that create instant customer appeal.	Sleek packaging of a premium perfume.
(f)	User-Friendliness & Upgradability	Must be easy to use, upgradeable, and have after-sales support.	Modular kitchen appliance with spare parts available.
(g)	Maintainability & Reproducibility	Should be easy to maintain and mass-produce.	Printer with replaceable cartridges and standard parts.
(h)	Balance: Standard vs. Customized Features	Combine basic standard features with optional custom features.	Car with standard safety + luxury add-ons.
(i)	Detailed Specification	Provide clear technical details.	Smartphone datasheet listing processor, battery, camera.
(j)	Safety & Sustainability	Must be safe, error-proof, and eco-friendly.	Biodegradable, non-toxic detergent.

🧠 Mnemonic: "Q-RACE MAPS"

Use Q-RACE MAPS to remember the 10 characteristics of good product design:

Letter	Stands For
Q	Product Quality
R	Reliable and worthy
A	Affordable (optimum cost)
C	Short Cycle time (design to market)
E	Eye-catching aesthetics
M	Maintainable and reproducible
A	After-sales support, compatibility, upgradability
P	Personalization - balance of standard and augmented features
S	Specification - detailed
S	Safe, error-proof, and eco-friendly

	💡 Final Insight
1.	Essence of Good Product Design Good product design is the foundation of both customer satisfaction and market success.
2.	Key Blend It combines quality, cost-efficiency, usability, and sustainability into one strong offering.

■ Concept Note: Introduction to Process Design

	✱ Process Design Overview
1.	Definition Process design ensures raw materials are transformed into finished goods efficiently, consistently, and cost-effectively.
2.	Role It bridges the gap between product design and production, aligning operations with customer expectations.
3.	Key Highlights • Focuses on how products are made • Plans workflows, equipment, layouts • Ensures quality, speed, scalability • Aligns with customer requirements & specifications
4.	Example In an automobile company, process design involves planning the assembly line, using robotic welding, and setting quality checkpoints.

■ Major Process Decisions - Process Choice

Process Types

Job Shop

Suitable for low volume, high variety, and customisation needs.

Batch Process

Ideal for moderate volume and variety with repeated production.

Repetitive Process

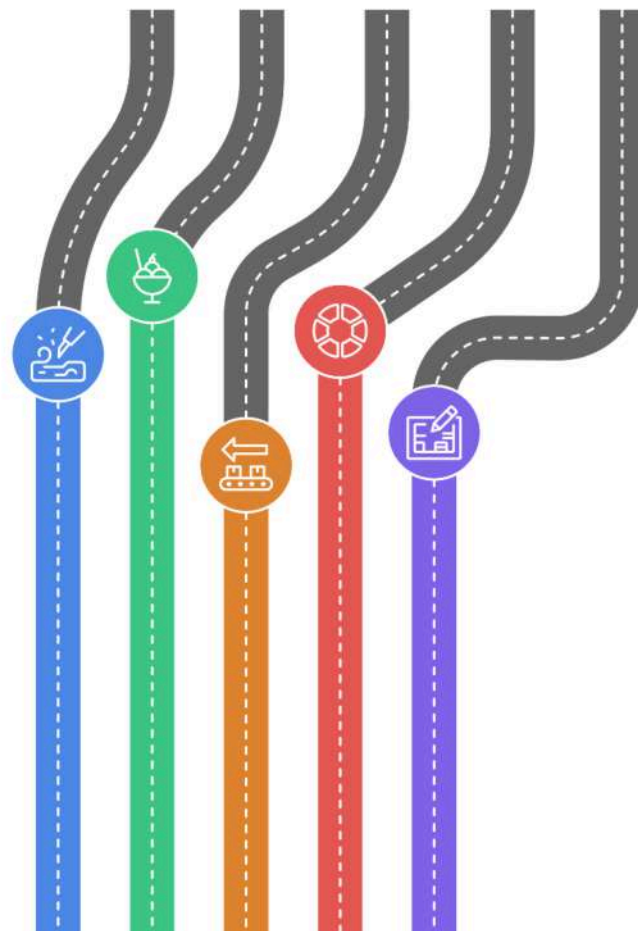
Best for high volume, standardised goods with slight flexibility.

Continuous Process

Perfect for very high volume, no variety, and 24/7 operation.

Project Process

Used for high customisation, large scope, and long duration projects.



Made with Napkin

Process Type	Key Features	Examples
1. Job Shop	• Low volume, high variety • Customisation (made-to-order) • High flexibility & skilled labour • Intermittent processing • Resources organised around process ☑ Strategy: Flexible flow	Tool & die shop
2. Batch Process	• Moderate volume & variety • Higher volume than job shop • Same/similar products made repeatedly	Paint, ice cream, soft drinks, books, magazines
3. Repetitive Process (Assembly Line)	• High volume, standardised goods • Slight equipment flexibility • Lower labour skill needed • Materials move in a line flow • Resources organised around product Suitable for: Make-to-stock, Assemble-to-order, Mass customisation	Automobiles, TVs, computers, toys
4. Continuous Process	• Very high volume, no variety • Highly standardised products • No flexibility, capital-intensive • Runs 24/7 ☑ Strategy: Rigid line flow	Petroleum, steel, sugar, flour, paper, cement, fertilisers
5. Project Process	• High customisation, large scope • Long duration, many activities • Needs substantial resources • Equipment flexibility & labour skill vary	Dam construction, bridge, hospital, publishing a book, new product development

☞ Mnemonic: "Just Be Ready, Create Projects"

Letter	Process Type	Key Trait
J	Job Shop	Custom, flexible, low volume
B	Batch	Moderate volume & variety
R	Repetitive	High volume, standardised goods
C	Continuous	Very high volume, no variety
P	Project	High customisation, large scope

Concept Note: Product Life Cycle (PLC)

1. **Definition**
The **Product Life Cycle (PLC)** shows a product's journey from **introduction** to **decline**.
2. **Impact**
Each stage influences **marketing, pricing, cost, and strategic decisions**.

Stages of Product Life Cycle

Stage	Consumer Awareness	Sales Volume	Profit Volume	Competition	Cost Level	Key Highlights	Example
1. Introduction	Low	Low	Low or Negative	Low	High (due to promotions)	• Product is new to market, High promotional expenditure, Pricing depends on innovation & target segment	Electric scooters by Lime & Bird
2. Growth	Increasing	Rapidly Increasing	Increasing	Increasing	Decreasing (economies of scale)	• Focus on market share, Cost reduction, Adjusted promotions	Android smartphones by Samsung & HTC
3. Maturity	High	Peak, then stabilizes	High but stable	Intense	Stable (focus on efficiency)	• Market saturation, Product differentiation, Aggressive promotions	Coca-Cola, Pepsi
4. Decline	High but waning	Declining	Declining	Decreasing	Cost-cutting focus	• Sales drop, Narrowing margins, Strategic decisions (revive or discontinue)	DVD players vs. streaming services

Key Takeaways by Stage

Stage	Key Features	Marketing & Strategy Focus	Profit & Competition
Introduction	- Low sales & volume - High promotional costs - Pricing may include early adopter discounts - Consumer awareness: Low	Build awareness and attract early adopters	Profit often negative; low competition
Growth	- Rapid revenue growth - Cost reductions through scale - Adjust promotions for growth - Consumer awareness increasing	Expand market share, refine pricing & distribution	Profit rising; competition increasing
Maturity	Market saturation	Focus on differentiation,	Profit stable & high;



	- Product enhancements & variations - Aggressive promotions to retain share - Consumer awareness: High	retention, and brand loyalty	intense competition
Decline	- Falling sales & interest - Shrinking profit margins - Consider discontinuation or revival - Consumer awareness: Still high	Decide whether to phase out or revive product	Profit declining; competition falling

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

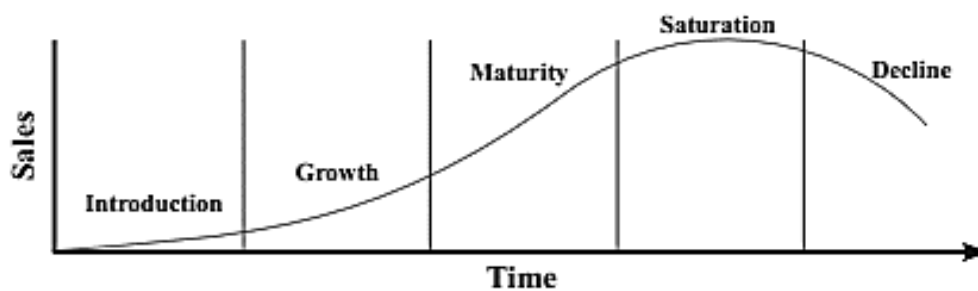


Figure 3.2: PLC for FMCG Product

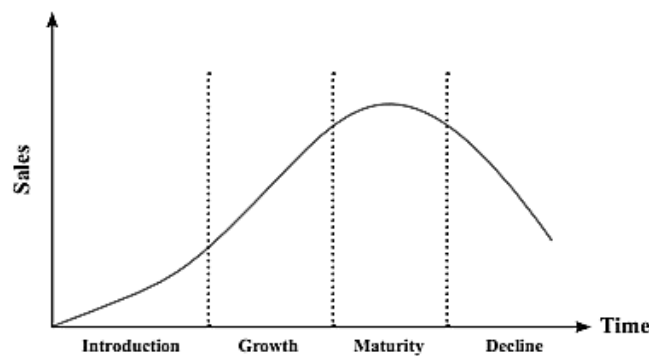


Figure 3.3: PLC for High Tech Product

2. 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

1. **Definition**
Decision on selecting processes to convert inputs (resources) into outputs (products/services) as per product specifications.
2. **Key Factors**
 - Long-term efficiency and productivity.
 - Resource availability.
 - Flexibility.
 - Cost and benefits.
 - Quality.
 - Lead time.
3. **Premises**
 - **Make vs Buy:** Fully/partially in-house or outsourced production.
 - **Capital intensity:** Balance between automation and manual operations.
 - **Process flexibility.**

Facility Focus Areas

1. **Process-Focused**
 - Facility designed around processes.
 - Equipment and workstations are flexible for frequent changes.
 - Suited for customization (Job shop production).
 - Example:** Aircraft production.
2. **Product-Focused**
 - Facility designed around products.
 - Suited for high volume, low variety production.
 - Achieves economies of scale and learning benefits.
 - Examples:** Steel, glass, paper, electric bulbs, chemicals, pharmaceutical products.
3. **Repetitive Focus**
 - Combines benefits of process- and product-focused strategies.
 - Uses modular production (Assembly production).
 - Examples:** Automobiles, household appliances.

■ Concept Note: Design Thinking and Its Stages

1. **Definition**
Design Thinking is a human-centered, solution-focused approach to innovation.
2. **Purpose**

Helps organizations solve complex problems creatively by understanding user needs and iteratively developing solutions.

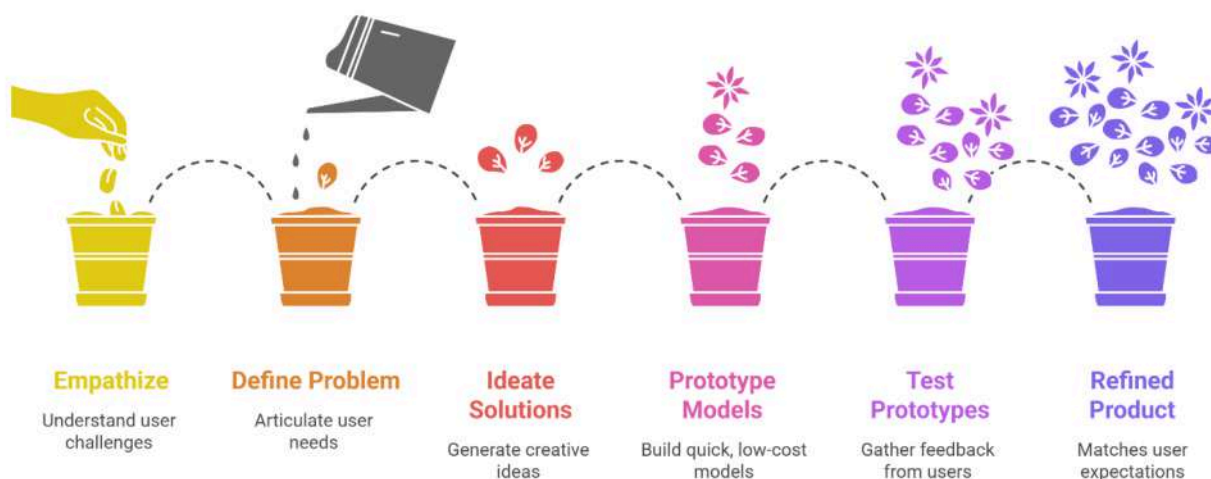
🧠 Mnemonic: E-D-I-P-T

Use E-D-I-P-T to remember the five stages of Design Thinking:

Letter	Stage
E	Empathize
D	Define
I	Ideate
P	Prototype
T	Test

📌 Stages of Design Thinking (with Tata Motors Example)

Design Thinking Process



Stage	Key Activity	Example & Insight
1. Empathize	Understand user needs, emotions, challenges via observation and engagement	Tata Motors studied urban commuters: traffic, fuel costs, parking issues ✂ Users wanted a compact, fuel-efficient, stylish city car
2. Define	Clearly articulate the problem based on user insights	Problem statement: "Urban commuters need a compact, affordable, stylish, efficient city car." ✂ Focus: Combine functionality with urban appeal
3. Ideate	Generate creative solutions without judgment	Tata teams brainstormed concepts: electric variants, modular interiors ✂ Outcome: Tata Tiago, a smart, youthful, budget-friendly hatchback
4. Prototype	Build quick, low-cost models to test ideas	Multiple Tiago prototypes with variations in design, dashboard, infotainment ✂ Goal: Test

		usability, aesthetics, performance before finalizing
5. Test	Try prototypes with real users, gather feedback, refine	Conducted test drives; adjustments to seats, dashboard, engine tuning ✎ Result: Refined product matching user expectations and market needs

✦ Key Takeaways

1.	User-centric, not product-centric
2.	Drives innovation through empathy and iteration
3.	Example: Tata Tiago launch demonstrates successful application of Design Thinking

MODULE 4. APPLICATION OF OPERATION RESEARCH - PRODUCTION PLANNING AND CONTROL

1. Introduction

Applications of Operations Research

1. **National Planning & Budgeting**
 - ✓ Preparation of **Five-Year Plans**
 - ✓ **Annual Budgets**
 - ✓ **Forecasting** income & expenditure
 - ✓ **Scheduling** major national projects
 - ✓ Estimating **GNP, GDP, Population, Employment**
 - ✓ Planning **Generation & Agricultural Yields**

Defence Service Operations

1. **Military / Defence**
 - ✓ Development of new **Technology**
 - ✓ **Optimization** of cost & time in defence projects
 - ✓ **Tender Evaluation** for technology & equipment
 - ✓ **Siting & Layout** of defence factories
 - ✓ **Threat-Analysis** assessment from enemy
 - ✓ **Battle Strategies & Tactics**
 - ✓ **Maintenance & Replacement** of equipment
 - ✓ **Defence Supplies Strategy** (war & peace)
 - ✓ **Vendor Evaluation** for canteen stores dept.
 - ✓ **Inventory Control**
 - ✓ **Transportation** during mobilization, operations, simulations
 - ✓ **Optimal Locations** of supply depots for operational units

Industrial Field

1. **Industry**
 - ✓ **Plant Location & siting**
 - ✓ **Finance Planning**
 - ✓ **Product & Process Planning**
 - ✓ **Facility Planning & factory layout**
 - ✓ **Purchasing, Vendor & Bid Evaluation**
 - ✓ **Inventory Control**
 - ✓ **Maintenance & Replacement** management
 - ✓ **Personnel Management** (merit rating, incentives)

2.	R&D & Engineering ✓ Technology Forecasting, Evaluation, Management ✓ Project Management of turnkey projects ✓ Systems Evaluation ✓ Tender Preparation & Negotiation ✓ Value Engineering & component selection ✓ Work/Method Study & Activity Sampling
3.	Business Management & Competition ✓ Decisions under Risk & Uncertainty ✓ Capital Investment & Returns ✓ Business & Area Selection ✓ Decision-Making under competition ✓ Business Strategy formation ✓ Optimum Advertisement Outlay ✓ Optimum Sales Force size & distribution ✓ Market Survey & Research Techniques
4.	Agriculture & Irrigation ✓ Project Management of irrigation projects/dams ✓ Low-cost Dam Construction ✓ Optimum Irrigation Canal Distribution ✓ Optimum Supply Points for seeds & fertilizers ✓ Optimum Collection Points for agricultural outputs
5.	Education & Training ✓ Optimum number & Location of Schools ✓ Balanced Student/Teacher Ratio ✓ Optimum Financial Outlay for national goals ✓ Optimum Examination Centers & student distribution ✓ Supply Depots for educational inputs ✓ Demand & supply of Textbooks & Stationery
6.	Public Works Dept. (PWD) ✓ Time & Cost Control of roads, bridges, buildings ✓ Project Completion Time Estimates ✓ Activity Time Estimates ✓ Machine/Equipment Selection ✓ Maintenance & Replacement ✓ Budget Preparation ✓ Tender Evaluation & bid selection
7.	Transportation & Communication ✓ Forecasting public transport needs ✓ Optimum Bus Routing ✓ Estimate of Income & Expense

- ✓ Railway Project Management (time & cost frame)
- ✓ Railway Network Distribution
- ✓ Telephone Demand Forecasting
- ✓ Optimum Exchange Capacity selection
- ✓ Optimum Busy-Hour Calls for exchanges

8. Home Management & Budgeting

- ✓ Expense Control to maximize savings
- ✓ Optimum Provision Purchases
- ✓ Order Quantity of provisions
- ✓ Time-Management
- ✓ Work & Time-Study in kitchen
- ✓ Item-Wise Budgets (provisions, petrol, dress, education, etc.)
- ✓ Investment Planning for surplus income
- ✓ Tax-Minimizing Investments
- ✓ Insurance of life & property
- ✓ Depreciation Estimates & optimum premiums

 Mnemonic for Recall

National Planning → Defence → Industry → R&D → Business → Agriculture → Education → PWD → Home → Mnemonic

 "No Dogs In Red Boots Are Eagerly Preparing Hot Meals."



This sentence helps you remember the first letter of each major sector:

Sector	Mnemonic Word	Explanation
National Planning and Budgeting	No	"National" starts with N
Defence Service Operations	Dogs	"Defence" starts with D
Industrial Field	In	"Industrial" starts with I
R&D and Engineering	Red	"Research" starts with R
Business Management and Competition	Boots	"Business" starts with B
Agriculture and Irrigation	Are	"Agriculture" starts with A
Education and Training	Eagerly	"Education" starts with E
Public Works Department	Preparing	"Public" starts with P
Transportation and Communication	Hot	"Transportation" starts with T
Home Management and Budgeting	Meals	"Home" starts with H

2. Production Planning and Control

Concept Book: Production Planning and Control (PPC)	
1.	Core Concept Production Planning & Control (PPC) is the nervous system of production. Like the human nervous system coordinates movement, PPC keeps all production activities in harmony .
2.	Primary Concern Delivery of products to customers or inventory as per a predetermined schedule .
3.	Key Activities ✓ Planned ✓ Coordinated ✓ Organised ✓ Controlled
4.	Objective Ensure timely delivery with optimal use of resources (men, machines, materials, money).

 Planning Horizons	
1.	Long-Term (7-10+ yrs) Plant construction, location, product-line design & development
2.	Medium-Term (2-5 yrs) Capital equipment budgeting, plant capacity & layout
3.	Short-Term (Months-1 yr) Inventory goals, wage budgets, labour/material/facility utilisation
	Example: ✓ Long-Term: Building a new factory in another city. ✓ Medium-Term: Buying new machines to increase output. ✓ Short-Term: Hiring seasonal workers for a festive rush.

Objectives of production planning and control	
1.	Ultimate Objective "To contribute to the profits of the enterprise."
2.	Achieved By ✓ Keeping Customers Satisfied ✓ Meeting Delivery Schedules
3.	 Specific Objectives "To establish the Routes and Schedules for work that ensure optimum use of Raw Materials, Labour, and Machines ."

Key Focus Areas of PPC

No.	Objective
(i)	Analysing orders to determine required raw materials and parts
(ii)	Answering customer/sales queries on order status

(iii)	Assisting costing department with cost estimates
(iv)	Supporting HR in manpower planning and job assignments
(v)	Controlling stock of finished parts/products
(vi)	Determining necessary tools for manufacturing
(vii)	Directing and controlling material movement through production
(viii)	Initiating changes in orders per customer requests
(ix)	Issuing requisitions for purchasing materials
(x)	Issuing requisitions for tools and parts (purchase/manufacture)
(xi)	Keeping up-to-date records of schedules and processes
(xii)	Maintaining stock of materials and parts
(xiii)	Notifying sales/accounting about order acceptance feasibility
(xiv)	Preparing route sheets and operation schedules
(xv)	Producing work orders to initiate production
(xvi)	Evaluating progress reports and initiating corrective actions
(xvii)	Receiving customer orders
(xviii)	Revising plans due to non-conformance or rush orders

Concept Book: Production Control Functions

- Definition**
Production control ensures every step of production is **Planned, Executed, and Monitored** to meet **Quality** and **Delivery** goals.

Production Control Functions (PRSDFI Mnemonic)

Letter	Function	Description	Example
P	Planning	Plan production operations in detail	Decide how many units to produce next quarter
R	Routing	Define the path & order of operations	Cutting → Welding → Painting
S	Scheduling	Fix quantity of work & timetable	500 units in 10 days
D	Dispatching	Issue orders & ensure time targets are met	Send work orders, prepare machines
F	Follow-up	Check progress & identify variances from plan	Review daily reports, adjust shifts
I	Inspection	Conduct quality checks of products	Random sampling of finished goods

Basic types of production control:

- Concept Book**
Basic Types of Production Control
 **Overview**
- Definition Recap**
Each type suits a specific **industry** or **production style**, and knowing them ensures the

right method for **efficient** operations.

Types of Production Control (Mnemonic: "Big Friendly Lions Often Show Bravery")

Letter	Type of Control	Industry Example	Description	Example
B	Block Control	Textiles, Printing	Keeps different jobs/materials separate	Different fabric types or magazine editions kept apart
F	Flow Control	Chemicals, Petroleum, Glass, Food Processing	Routing & scheduling fixed at plant layout	Continuous glass line: molten glass flows through stages
L	Load Control	Any industry with bottleneck machines	Controls load on critical machines	CNC machine slowing the entire line
O	Order Control	Job-lot shops, Intermittent systems	Control based on individual orders	Custom furniture shop making tables, chairs, cabinets
S	Special Project Control	Construction (bridges, schools, hospitals)	Team/engineer maintains close contact	Site engineer adjusts hospital project daily
B	Batch Control	Food Processing, Pharmaceuticals	Production done in fixed batches	Bakery makes 500 loaves, then switches to cookies

3. Control Measures - Time & Motion Study, Method Study, Work Study

Concept Book: Work Study & Its Components

Boosting Productivity Through Scientific Observation (Work Study)

Aspect	Definition / Purpose	Example
Work Study	Systematic examination of work systems to improve productivity & efficiency. Branches: ✓ Method Study → How the work is done ✓ Time Study → How long the work takes	—
Time Study	Technique of recording time to perform a job & setting a standard time. Purpose: ✓ Identify time wastage ✓ Set performance benchmarks ✓ Improve scheduling & planning	Worker takes 12 mins to assemble a wheel → after 10 cycles, avg. 10 mins becomes standard time.
Method Study	Systematic recording & critical examination of existing/proposed methods of work. Purpose: ✓ Eliminate unnecessary movements ✓ Simplify tasks ✓ Improve layout & process	Packaging unit: workers walk 5m for boxes → placing boxes nearby saves time & effort .
Motion Study	Analysis of movements of workers/machines to improve efficiency. Purpose: ✓ Reduce fatigue ✓ Improve ergonomics ✓ Increase speed & safety	Cashier reaches 50 times/hour → rearranged workspace keeps tools within reach, reducing strain & boosting speed.

4. Optimum Allocation of Resources - LPP

Concept Book: Linear Programming (LP)

Linear Programming (LP)

1.	Definition Technique for allocating limited resources to achieve an objective (least cost, max profit, least time) when resources have alternate uses .
2.	Why Needed ✓ Traditional tools like calculus / marginal analysis fail with inequality constraints. ✓ LP handles both equalities & inequalities effectively.

Basic Structure of an LP Problem

Component	Description	Example Purpose
1. Objective Function	Defines the goal of the problem → maximize (profit) or minimize (cost).	Maximize profit from product mix
2. Constraint Set	A system of equalities/inequalities representing limitations (resources, time, capacity).	Limited raw materials, labour hours

Definitions from Experts

1.	Kohlar LP builds a model of real situations with: (a) Variables (choices) (b) Mathematical expressions : (i) Variables linked to conditions (ii) Criteria to measure benefits (iii) Objective function. Ensures best alternative selection .
2.	Samuelson, Dorfman & Solow LP is analysis of problems where a linear function is maximized/minimized subject to linear inequalities .
3.	Loomba LP is part of the system approach to management , where programs are designed/evaluated based on business objectives .

Key Takeaways

1.	Optimization LP finds the best solution under constraints.
2.	Objective Function Defines what to maximize or minimize .
3.	Constraints Represent limitations (equalities/inequalities).
4.	LP vs Calculus LP can handle inequalities ; calculus cannot.

5. System Approach
LP aids in strategic business planning.

Concept Book: Application Areas of Linear Programming

 Mnemonic to Remember: IMMA-Not Father

1. (Industrial, Management, Miscellaneous, Administrative, Non-Industrial, Further Applications)

1. Industrial Applications

 Objective: Plan production & procurement while meeting demand and constraints.

Example	Application
a. Product Mix Problem	Best combination of products
b. Production Scheduling	Time-based allocation of resources
c. Production Smoothing	Balance fluctuations in demand
d. Blending Problems	Mix raw materials for optimal result
e. Transportation Problems	Minimize transport cost/time
f. Distribution Problems	Efficient allocation of finished goods
g. Trim Loss	Reduce cutting/scrap loss
h. Oil Refineries	Optimal product mix from crude
i. Communication Industry	Transmission, switching, relaying
j. Railroad Industry	Freight & train scheduling

2. Management Applications

Used for decision-making, planning, and resource allocation.

Example	Application
a. Portfolio Selection	Balance risk & return
b. Financial Mix Strategy	Optimal financing sources
c. Profit Planning	Maximize margins
d. Media Selection	Best advertising mix
e. Travelling Salesman Problem	Minimize travel cost/distance
f. Equitable Salaries	Fair pay distribution
g. Staffing Problem	Assign right staff at right time

3. Miscellaneous Applications

Example	Application
a. Farm Planning	Crop/livestock mix, acreage allocation
b. Airline Routing	Optimal flight scheduling
c. Administration, Education, Politics	Resource & policy planning
d. Diet Problems	Economical hospital diets

4. Administrative Applications

Focus on optimal use of men, machines, and materials in operations.

5. Non-Industrial Applications

Example	Application
Agriculture	Crop and irrigation planning

Environmental Protection	Resource conservation
Urban Development	Housing & infrastructure
Facilities Location	Placement of hospitals, depots, schools

🚀 6. Further Applications

Example	Application
Structural Design	Maximize product strength/capacity
Assembly Line Balancing	Minimize idle time
Military Tanker Fleet Scheduling	Optimize logistics
Make-or-Buy Decisions	Evaluate profitability
Equipment Selection & Method Evaluation	Choose best tech/process
Sales vs Plant Capacity	Match demand with supply
Purchasing Policies	Design optimal procurement strategy

🧠 Quick Recap Table (IMMA-Not Father)

Mnemonic Letter	Application Area
I	Industrial Applications
M	Management Applications
M	Miscellaneous Applications
A	Administrative Applications
N	Non-Industrial Applications
F	Further Applications

📖 Concept Book: Key Concepts in Linear Programming Solutions

🧠 Solutions in Linear Programming

Concept	Definition	Key Point
1. Feasible Solution	Any solution that satisfies all constraints of the LPP.	Lies within/on boundary of feasible region. May or may not be optimal .
2. Basic Solution	Obtained by setting (n - m) variables = 0 and solving m equations (where n = variables, m = constraints).	May/may not satisfy non-negativity . May/may not lie inside feasible region .
3. Basic Feasible Solution (BFS)	A basic solution that also satisfies all constraints including non-negativity .	Lies inside feasible region.
4. Optimal Feasible Solution	A feasible solution that maximizes/minimizes the objective function.	Best among all feasible solutions. Found using Simplex / Graphical Method .
5. Degenerate Solution	A BFS where two or more basic variables = 0 .	Indicates redundancy / tie in constraints.

🧠 Summary Table

1.	Feasible Solution Satisfies all constraints

2.	Basic Solution Found by solving m equations with $(n - m)$ variables set to zero
3.	Basic Feasible Solution Basic solution that also satisfies all constraints including non-negativity
4.	Optimal Feasible Solution Feasible solution that gives the best value of the objective function
5.	Degenerate Solution BFS with two or more basic variables equal to zero

■ Concept Book: Key Elements in Linear Programming

✦ Essential Components of the Simplex Method

Concept	Definition	Purpose	Example
Slack Variable	Added to a $\leq$ constraint to convert it into an equation.	• Shows unused resources • Converts inequality $\rightarrow$ equality	$2x_1 + 4x_2 \leq 30$ $2x_1 + 4x_2 + s_1 = 30$ $s_1 = 30$
Surplus Variable	Subtracted from a $\geq$ constraint to convert it into an equation.	• Shows excess over minimum requirement • Maintains equality	$2x_1 + 4x_2 \geq 30$ $2x_1 + 4x_2 - s_1 = 30$ $s_1 = 30$
Artificial Variable	Temporarily added when slack/surplus can't provide a feasible solution.	• Helps start Simplex when no basic feasible solution exists • Removed later by Big M or Two-Phase Method	$X + y - s + A = 10$ $x + y - s + A = 10$, where A = artificial variable
Big M Method	Technique to eliminate artificial variables .	• Assigns very large penalty (M) in objective function • Drives artificial variables out during optimization	$\text{Max } Z = 3x + 2y - M \cdot A$ $Z = 3x + 2y - M \cdot A$
Simplex Table	Tabular format used for Simplex iterations.	• Organizes constraints, variables & calculations • Identifies entering & leaving variables	Contains: Basic Variables, Constraint Coefficients, RHS, Z-row, Ratio Column

🧠 Summary Table

1.	Slack Variable Converts $\leq$ constraints to equations; shows unused resources
2.	Surplus Variable Converts $\geq$ constraints to equations; shows excess over minimum
3.	Artificial Variable Temporarily added to help start Simplex when no BFS exists

4.	Big M Method Penalizes artificial variables to remove them from final solution
5.	Simplex Table Tabular tool for performing iterations and tracking optimization steps

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

 **Concept Book: Primal & Dual in Linear Programming**

 **Primal and Dual Problems in Linear Programming**

Aspect	Primal Problem	Dual Problem
Definition	The original LP problem .	The problem derived from the primal.
Objective	Usually Maximization (or Minimization).	Objective type reverses (Max $\leftrightarrow$ Min).
Constraints / Variables	Has constraints involving $\leq$, $\geq$, or $=$.	Each constraint of primal $\leftrightarrow$ becomes a variable in dual.
Relations	Constraints are $\leq$ or $\geq$.	Relations are reversed ($\leq \leftrightarrow \geq$).
Coefficients	Coefficients in objective & constraints are original.	Constraint coefficients $\leftrightarrow$ become objective coefficients .
Example	Max $Z = 10x_1 + 8x_2$ s.t. $2x_1 + 3x_2 \leq 30$ $4x_1 + 5x_2 \leq 50$ $x_1, x_2 \geq 0$	Min $Z' = 30y_1 + 50y_2$ s.t. $2y_1 + 4y_2 \geq 10$ $3y_1 + 5y_2 \geq 8$ $y_1, y_2 \geq 0$

 Summary Table	
1.	Primal Original LP problem
2.	Dual Derived from primal; flips roles of constraints
3.	Use Solving one gives insights into the other
4.	Benefit Helps in sensitivity analysis and economic value

5. Transportation

Concept Book: Transportation Problem in Linear Programming

🚚 Transportation Problem

1.	Origins 🔗 1941 - F.L. Hitchcock → "Distribution of a product from several sources to numerous locations" → Introduced efficient goods transportation . 🔗 1947 - T.C. Koopmans → "Optimum utilization of the transportation system" → Expanded model for optimized transport networks .
2.	Definition The Transportation Problem is about moving products from supply origins (factories) to demand destinations (warehouses) while minimizing transportation cost .
3.	Objective Determine how many units to transport from each origin → destination such that: ☑ Destination demands are satisfied ☑ Plant capacities are respected ☑ Total transportation cost is minimized

🚚 Real-World Applications

Widely used in **supply chain management** to optimize logistics and distribution:

📦 Flow Direction	📍 Example
🏭 Plants → Warehouses	Factory shipments to storage units
🏪 Warehouses → Wholesalers	Distribution centers to bulk buyers
🛒 Wholesalers → Retailers	Bulk suppliers to retail outlets
👤 Retailers → Customers	Final delivery to end users

🧠 Key Takeaways

1.	Origins Developed by Hitchcock (1941) and Koopmans (1947)
2.	Definition Transport goods from supply to demand points at minimum cost
3.	Objective Meet demand, respect supply limits, and minimize cost
4.	Applications Crucial in logistics, supply chain, and distribution planning

🚚 Methods in Transportation Problem

Method	What It Is	Steps (Simplified)	Highlights
🕒 North-West Corner Rule (NWCRC)	Start allocation from top-left (north-west) cell of cost	1. Allocate max possible to top-left cell 2. Adjust supply/demand 3. Move → if demand met, ↓ if	☑ Simple & fast ✗ Ignores cost 🔗 Good for feasibility , not

	matrix.	supply exhausted 4. Repeat until done	optimality
💰 Least Cost Entry Method (LCEM)	Allocate to the cell with the lowest cost first.	1. Find lowest cost cell 2. Allocate max possible 3. Cross out row/col once satisfied 4. Repeat with next lowest	☒ Cost-aware ☒ Still heuristic ☒ More cost-efficient than NWCR
🧠 Vogel's Approximation Method (VAM)	Uses penalty values to guide towards cost-effective cells.	1. Compute penalty = (lowest - 2nd lowest cost) per row/col 2. Choose row/col with highest penalty 3. Allocate to lowest cost cell in that row/col 4. Adjust supply/demand & repeat	☒ Most accurate among initial methods ☒ Often close to optimal ☒ Balances cost & allocation
📊 MODI Method (Modified Distribution)	An optimality test to improve initial feasible solution.	1. Compute dual variables U, V 2. Find opportunity cost: $d_{ij} = c_{ij} - (U_i + V_j)$ 3. If all $d_{ij} \geq 0 \rightarrow$ optimal 4. If any $d_{ij} < 0 \rightarrow$ improve with loop/pivot	☒ Guarantees optimality ☒ Applied after NWCR, LCEM, or VAM ☒ Reduces total transport cost

🧠 Summary Table

📊 Method	🔗 Strategy Used	🧠 Strengths	⚠️ Limitations
North-West Corner Rule	Start from top-left cell	Simple and quick	Ignores cost
Least Cost Entry	Allocate to lowest cost cell	Cost-aware, better than NWCR	Still heuristic
Vogel's Approximation	Use penalty to guide allocation	Most accurate, near-optimal	Slightly more complex
MODI Method	Optimize current solution	Ensures optimality	Requires initial feasible solution

📖 Concept Book: Special Cases in Transportation Problem

⚡ Exceptions in the Transportation Problem

Exception	What It Is	How to Handle	Why It Matters
1. Unbalanced TP	Total Supply $\neq$ Demand	• Excess Supply $\rightarrow$ Add dummy destination (cost = 0) • Excess Demand $\rightarrow$ Add dummy origin (cost = 0)	Balancing makes problem solvable by methods like VAM & MODI
2. Maximization	Goal is to maximize	Convert to minimization	Allows use of

TP	profit, benefit, or efficiency (not minimize cost)	using opportunity loss matrix	standard transportation methods
3. Prohibited Transportation	Some routes are not allowed (physical, legal, strategic limits)	Assign very high cost (M) or mark cell infeasible	Prevents allocation to restricted routes
4. Degeneracy	Allocated cells $< (m + n - 1)$ (m = origins, n = destinations)	Insert a very small allocation (ϵ) in unoccupied cell(s)	Degeneracy disrupts MODI calculations ; ϵ restores feasibility

Summary Table

 Special Case	 Description	 Handling Strategy
Unbalanced Problem	Supply $\neq$ Demand	Add dummy row/column with zero cost
Maximization Problem	Goal is to maximize profit	Convert to minimization using cost transformation
Prohibited Transportation	Certain routes are blocked	Assign very high cost or mark as infeasible
Degeneracy	Allocated cells $< (m + n - 1)$	Add small value (ϵ) to maintain feasibility

6. Job Evaluation, Job Allocation - Assignment

Concept Book: Assignment Problem & Hungarian Method

 Assignment Problem	
1.	What It Is Assign people, machines, or resources to tasks , each with a different cost .
2.	Objective ☒ Minimize total cost ☒ Ensure one-to-one assignment (each task $\leftrightarrow$ one resource).

Methods to Solve Assignment Problem

Method	Description
1. Complete Enumeration	Try all combinations (impractical for large problems).
2. Simplex Method	LP-based approach.
3. Transportation Method	Treats assignment as a special case of transportation.
4. Hungarian Method	Most efficient & widely used technique.

Hungarian Method (Step-by-Step)

Step	Process	Result
Step 1: Row Operation	Subtract smallest element in each row from all row elements.	At least 1 zero per row $\rightarrow$ Reduced Cost Table
Step 2: Column Operation	Subtract smallest element in each column from all column elements.	At least 1 zero per column
Step 3: Optimality Check	Cover all zeros with minimum lines . If	If not $\rightarrow$ go to Step 4

	(lines = rows/columns) → Optimal solution.	
Step 4: Improved Matrix	Find smallest uncovered element : ✓ Subtract from all uncovered ✓ Add to intersections of 2 lines ✓ Leave others unchanged	Adjusted matrix → more zeros created
Step 5: Repeat	Repeat Steps 3 & 4 until (lines = rows/columns).	Optimality achieved
Step 6: Final Assignment	Assign based on zero elements : ✓ Row with single zero → assign & cross column ✓ Column with single zero → assign & cross row ✓ If none → choose arbitrarily	☒ Final assignment (may be multiple solutions)

	 Key Takeaways
1.	Assignment Problem Allocate resources to tasks at minimum cost
2.	Hungarian Method Efficient step-by-step method for optimal assignment
3.	Optimality Check Use lines to cover zeros and test solution
4.	Final Assignment Based on zero positions in the reduced matrix

7. Scheduling and Queuing Models

Concept Book: Scheduling in Production Planning

	 Scheduling in Production
1.	Concept (What is Scheduling?) Definition: Process of deciding start & completion timings for each operation in production. Key Objectives: ✓ Maximize machine & operator utilization ✓ Avoid burden/delays ✓ Decide task order & start time ✓ Plan total operation & production time
2.	Purpose of Scheduling Ensures:  Efficient use of time, machines, manpower  Clear sequence of operations  Proper time allocation per task

📦 Considers: Routing, Production method, Quantity, Material transport, Capacity, Delivery dates

🔗 Relationship Between Routing & Scheduling

📦 Routing	⌚ Scheduling
Defines sequence of operations	Determines timing for each operation
Specifies tools, equipment, personnel	Allocates start and finish times
Is a prerequisite for scheduling	Informs routing with time schedules
Focuses on efficiency of path	Focuses on efficiency of time usage

Key Insight

Routing and Scheduling are interconnected and interdependent.

They must work together for effective production planning and control.

🏭 Factory Example: Routing vs Scheduling

Process	Routing (Sequence of Operations)	Scheduling (Time Allocation)
Cutting	Cutting first	9:00 - 10:00 AM
Shaping	Then Shaping	10:00 - 11:30 AM
Polishing	Then Polishing	11:30 AM - 1:00 PM
Packaging	Finally Packaging	1:00 - 2:00 PM

Together → Routing = "What order?" + Scheduling = "What time?" → Ensures efficiency & timely delivery.

🧠 Key Conclusion

Insight	Explanation
✅ Complementary	Routing + Scheduling work hand-in-hand.
✅ Essential	Both needed for maximum production efficiency.
⚠️ Without Scheduling	Routing lacks timing clarity.
⚠️ Without Routing	Scheduling lacks operational structure.

📖 Concept Book: Lean Operations - Priority Rules

- 🎯 Definition
Priority Rules are guidelines to decide which job goes next in production.
- Purpose
 - ✓ Improve efficiency
 - ✓ Reduce delays
 - ✓ Maximize resource utilization

🧠 Common Priority Rules

📖 Priority Rules in Scheduling (Lean Operations)

Rule	What It Is	✅ Advantage	❌ Limitation
1. First Come First Served (FCFS)	Jobs processed in arrival order	Simple & fair	Not optimal for urgent/short jobs
2. Shortest	Process shortest jobs	Minimizes	Long jobs may get delayed



Operations / Processing Time (SOT / SPT)	first	average waiting time	
3. Early Due Date (EDD)	Process jobs by earliest due dates	Meets delivery deadlines	Ignores job size/urgency
4. Least Slack (LS)	Process jobs with least slack time	Prioritizes jobs at risk of delay	Needs accurate time estimates Slack = (Days until Due Date - Work Remaining)
5. Critical Ratio (CR)	Process jobs with lowest CR value CR = Days until Due Date ÷ Work Remaining	Balances urgency + processing time	CR values fluctuate with updates CR > 1 = Ahead CR < 1 = Behind CR = 1 = On schedule
6. Last Come First Served (LCFS)	Process latest arriving job first	Useful in dynamic environments	Older jobs may be delayed
7. Longest Processing Time (LPT)	Process longest jobs first	Keeps machines busy	Short jobs wait unnecessarily

Summary Table

Rule	Strategy Used	Best For
FCFS	Order of arrival	Fairness, simplicity
SPT	Shortest job first	Reducing average wait time
EDD	Earliest due date	Meeting deadlines
LS	Least slack time	Urgent jobs with tight schedules
CR	Lowest critical ratio	Balanced scheduling
LCFS	Latest job first	Fast-changing environments
LPT	Longest job first	Maximizing machine utilization

Queuing models

	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.

6. Elaboration on System Utilization

- 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.

Symbol	Represents
λ	Customer arrival rate
M	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
P	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

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

- ✓ 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'

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

8. Simulation and Line Balancing

Concept Book: Monte Carlo Simulation

Monte Carlo Simulation

1. Definition

A **statistical technique** that uses **random sampling** to model and analyze systems with **uncertainty**. Instead of one fixed prediction → gives a **range of possible outcomes**.

2. Origin

Named after **Monte Carlo Casino (Monaco)** where **chance & randomness** dominate. Developed in **WWII** by **Stanislaw Ulam** and **John von Neumann** to solve **complex physics problems**.

Why Use Monte Carlo Simulation?

 Scenario	 Simulation Benefit
Uncertain demand or costs	Predicts a range of outcomes
Complex systems with many variables	Models interactions and dependencies
Risky decisions	Evaluates probability of success or failure
Limited historical data	Generates synthetic data for forecasting

Key Steps in Monte Carlo Simulation

Step	Action	Purpose
1. Define the Problem	State what you want to predict/optimize	Sets the goal of the simulation
2. Build the Model	Identify relationships between inputs & outputs	Creates the mathematical framework
3. Identify Input Distributions	Assign probability distributions (normal, uniform, etc.) to uncertain variables	Captures uncertainty in inputs
4. Generate Random Numbers	Simulate thousands of random scenarios	Provides variability for analysis
5. Run the Simulation	Calculate outcomes for each simulated case	Produces a range of results
6. Analyze Results	Examine distribution of outcomes	Enables informed decisions under uncertainty

Example: Inventory Management

1. **Inputs**
Demand (**random**), Lead Time, Holding Cost
2. **Simulation**
Run **10,000 trials** with random demand values
3. **Outcome**
Probability distribution of total cost → guides **reorder levels** & **safety stock** decisions

 **Key Insight:** Monte Carlo doesn't give a single answer—it shows the **full range of possible outcomes**, letting managers plan with **risk awareness**.

Applications in Operations Management

 Area	 Use Case
Inventory Management	Forecast costs under demand uncertainty
Project Management	Estimate completion time and resource needs
Financial Forecasting	Predict cash flow, ROI, and risk
Queuing Systems	Analyze wait times and service efficiency
Resource Allocation	Optimize manpower and machine usage
Supply Chain Planning	Evaluate delivery risks and buffer strategies

Key Takeaways

1. **Monte Carlo**
Uses **randomness** to simulate real-world uncertainty
2. **Benefit**
Reveals **full range of possible outcomes**
3. **Application**
Widely used in operations, finance, and engineering
4. **Decision Support**
Helps make **data-driven, risk-aware decisions**

9. Lean Operations

1. **Roots of Lean Operation**
 - Originated in Toyota Automobile Co., Japan. - Waste was avoided at all costs:
 - (i) Time waste: Repairing faulty products.
 - (ii) Inventory waste: Avoid high inventories.
 - (iii) Idle worker waste: Minimize idle workers.
2. **Elements of Lean Production**
 - (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.

■ Concept Book: Lean Operations & Just-In-Time (JIT)

✦ Streamline your production, eliminate waste, and deliver excellence—on time, every time.

4.9 Lean Operations

🌱 Roots of Lean Operation

Origin	Focus	Types of Waste Eliminated
Toyota Automobile Co., Japan	Aim: Eliminate waste at all levels	🕒 Time Waste → Avoid rework & repairs 📦 Inventory Waste → Maintain low inventory 👤 Idle Worker Waste → Keep workers productively engaged

🔗 Elements of Lean Production

Lean production is built on efficiency, teamwork, and quality.

Key elements include:

1.	🌀 Value Stream View See the organization as a flow of value from suppliers to customers
2.	👥 Teamwork Organize workers into teams with clear roles
3.	🎯 Quality Focus Aim for perfect quality and continuous improvement
4.	🏭 Cellular Manufacturing Use product-based layouts instead of functional ones
5.	🕒 Just-In-Time Mode Produce only what is needed, when it's needed

10. Just-In-Time (JIT)

🎯 Objectives of JIT Manufacturing

JIT is all about producing exactly what the customer wants, with zero waste and perfect timing.

🎯 Goal	
1.	☒ Customer Focus Produce what and when the customer needs
2.	☒ Quality Assurance Ensure perfect quality in every unit
3.	☒ Speed Minimize lead times and delays
4.	☒ Feature Control Add only necessary features
5.	☒ Waste Elimination Avoid waste in labour, materials, and equipment
6.	☒ Skill Development Use methods that enhance worker capabilities

	📋 Overview of JIT Activities
1.	 Inventory Reduction Lower stock at all stages—raw, WIP, finished goods
2.	 Quality Improvement Enhance quality inside and outside the organization
3.	 Lead Time Reduction Cut down setup and movement times
4.	 Vendor Control Work with fewer, high-performing suppliers
5.	 Continuous Improvement Fix problems and seek new ways to improve
6.	 Total Preventive Maintenance Avoid breakdowns and delays proactively
7.	 Strategic Gain Build a competitive edge in the market

	💡 Key Takeaways
1.	Lean Operations Focus on waste elimination and value creation
2.	JIT Manufacturing Produce only what's needed , with zero excess
3.	Shared Goal Both aim for efficiency, quality, and customer satisfaction

MODULE 5. PRODUCTIVITY MANAGEMENT AND QUALITY MANAGEMENT

1. Measurement Techniques of Productivity Index

■ Concept Book: Productivity

Unlocking efficiency through smarter use of resources

1.	Definition & Concept Productivity is the link between outputs and inputs . It shows how well resources are used to make goods or services. It's about finding better, cheaper, quicker, safer ways to work. It reflects the economic efficiency of resource use and the success of a production system.
2.	Characteristics ✓ A quantitative relationship between what is produced (output) and what is used (input). ✓ Productivity improves when: ➤ More output is achieved with less input. ➤ The output/input ratio rises.
3.	Measurement Productivity Index ✓ A numerical ratio of output to input. ✓ An upward trend = improved productivity. Formula: $P = O / I$ Where: P = Productivity O = Output (goods/services) I = Input (materials, labour, machines, energy, etc.)

🧠 Examples of Productivity

1.	Labour Productivity Ratio of goods produced to the number of workers or man-hours
2.	Material Productivity Output per tonne of raw material used
3.	Energy Productivity Output per kilowatt of electricity consumed

Example:

If a factory produces 1,000 units using 100 man-hours, then Labour Productivity = $1000/100 = 10$ Units per hour



Key Takeaways

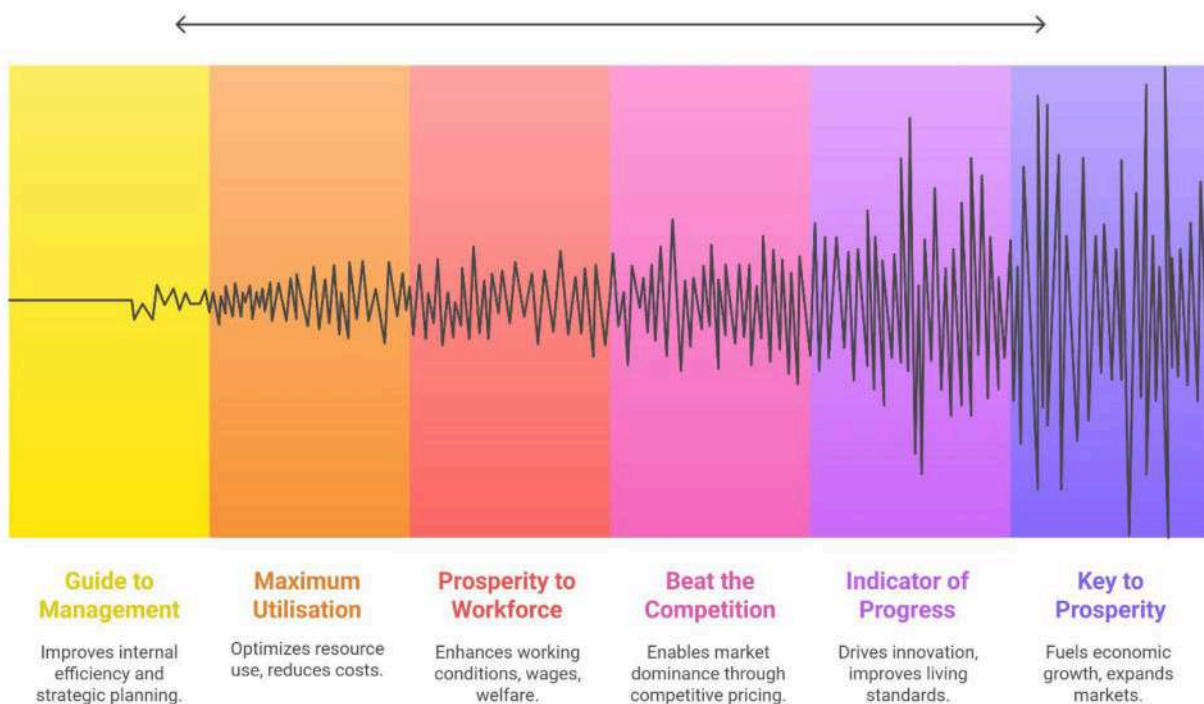
- Definition**
Relationship between output and input
- Mindset**
Focused on better, faster, safer task execution
- Measurement**
Productivity Index ($P = O/I$)
- Goal**
Maximize output, minimize input

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

Concept Book: Importance of Productivity

❖ Productivity isn't just a number—it's the engine of growth, competitiveness, and prosperity.

Importance of concept Productivity



Why Is Productivity Important?

- Beat the Competition**
 - ✓ In a **competitive market**, customers have many choices.
 - ✓ Higher **productivity** → goods are produced **faster, cheaper, better** → stronger competitiveness.

Example: A **smartphone company** making high-quality phones at **lower cost** outperforms rivals.
- Guide to Management**
 - ✓ **Productivity indices** help managers make better decisions.
 - ✓ **Strategic:** Compare firms, find gaps, take action. ◇

	✓ Tactical: Compare departments, improve weak units. ✓ Planning: Analyze inputs, pick cost-effective resources. ✓ Administration: Track progress, aid labour negotiations & policies. Example: A textile company uses data for fair wage talks & efficiency.
3.	Indicator of Progress ✓ In developing countries, rising productivity = economic progress. ✓ Reflects continuous improvement (better, faster, safer). Example: Mobile banking in rural areas improves service delivery.
4.	Utilization of Scarce Resources ✓ Ensures limited resources are used wisely & efficiently. ✓ Benefits: lower costs, customer satisfaction, less worker fatigue. Example: A factory redesigns layout to cut walking time → saves energy & boosts output.
5.	National Prosperity ✓ Higher productivity = → More goods with same inputs → Lower prices for consumers → Better wages for workers → Higher profits for firms. Nations like Japan, China, South Korea owe growth to productivity focus.
6.	Prosperity to Workforce ✓ Boosts worker welfare: → Better conditions → Higher pay → More benefits. Leads to higher living standards. Example: Automation reduces repetitive tasks → workers shift to skilled roles, feel more satisfied.

7. Other Benefits of Productivity	
1.	Increased Profits Funds available for expansion and modernization
2.	Enhanced Goodwill Cheaper goods, satisfied staff, strong financial position
3.	Export Competitiveness Lower production costs and better quality for global trade

Key Takeaways	
1.	Competition Productivity helps firms survive and thrive
2.	Management Tool Guides strategic, tactical, and planning decisions
3.	National Growth Drives prosperity and innovation
4.	Worker Welfare Improves wages, conditions, and quality of life
5.	Global Impact Boosts export strength and international reputation

🧠 Mnemonics to remember: BIG MAP COP

- Beat the Competition
- Indicator of Progress
- Guide to Management
- Maximum Utilisation
- Administration
- Planning
- Competitive Strength
- Other Uses
- Prosperity

📖 Concept Book: Criteria for Measuring Productivity

Measurement of Productivity



📊 Productivity Measurement

Meaning

Productivity measurement shows how efficiently resources are used to produce goods or services.

It's about working smarter, not just harder.

1. Change in Output per Unit of Input

Measures output produced for each unit of input.

What It Shows:

- Performance improvement of an input.
- Higher output per input = greater efficiency.

2. Change in Input per Unit of Output

Measures how much input is required for one unit of output.

What It Shows:

- Resource consumption per unit.
- Lower input per output = higher efficiency.

🧠 Key Takeaways

📋 Criterion	🔗 What It Measures	🎯 Goal
Output per Unit of Input	Efficiency of input usage	Maximize output
Input per Unit of Output	Resource consumption per unit	Minimize input

Productivity Indices



	Man-hour Output Measures output per hour of work
	Productivity Ratio Assesses output relative to input
	Financial Ratios Evaluates return on capital employed
	Materials Productivity Measures output per unit of material
	Capital Productivity Measures output per unit of capital
	Energy Productivity Measures output per unit of energy
	Combined Productivity Measures total output from all inputs
	Additional Input Factors Includes other inputs like insurance and taxes

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

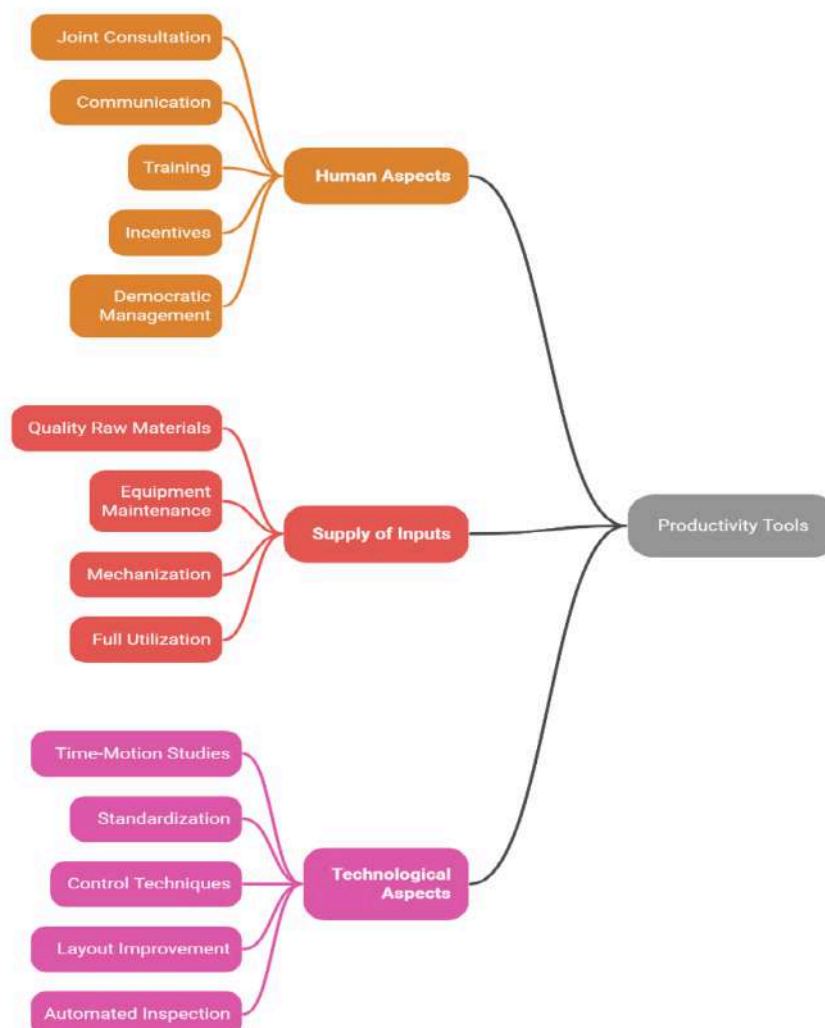
Other inputs (e.g., insurance, taxes, advertising) can also have productivity measured similarly.

Data Availability

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

■ Concept Book: Tools to Improve Productivity

Tools to Increase Productivity



	✦ Productivity Insight
1.	Core Idea Productivity isn't about working harder —it's about working smarter, together .
2.	What Are Productivity Tools? ✓ Strategies, systems, techniques that improve input performance. ✓ Aim: remove inefficiencies and achieve more output with less effort, cost, and time.

1. Human Aspects

	Focus: Empowering People
1.	Worker Participation Involve employees in decision-making through joint consultation
2.	Communication Improve internal communication to reduce delays and confusion
3.	Trust & Cooperation Build strong relationships via better job procedures, training, and incentives
4.	Management Efforts Plan work better, promote democratic leadership , and enhance human relations

✦ Example:

A company introduces a profit - sharing scheme and sees a 15% rise in output due to motivated workers.

2. Supply of Inputs

	◇ Focus: Enhancing Resource Quality & Utilization
1.	Raw Material Quality Use better materials to reduce defects and rework
2.	Equipment Provision Ensure modern machines and regular maintenance
3.	Mechanization Replace manual tasks with automated equipment
4.	Full Utilization Maximize use of manpower and machinery capacity

Example:

Switching to automated packaging reduces labour cost and increases speed by 30%.

3. Technological Aspects

	Focus: Process Optimization & Innovation
1.	Time & Motion Studies Analyze tasks to find faster, safer methods
2.	Simplification & Standardization Reduce complexity and ensure uniform quality

3.	Control Techniques Apply production planning, cost control, and quality control
4.	Layout Improvement Redesign plant/shop layout for efficient flow and less movement
5.	Inspection Techniques Improve checks to reduce waste and defects

Example:

A factory redesigns its layout to shorten walking paths—saving 2 hours per worker per week.

Key Takeaways

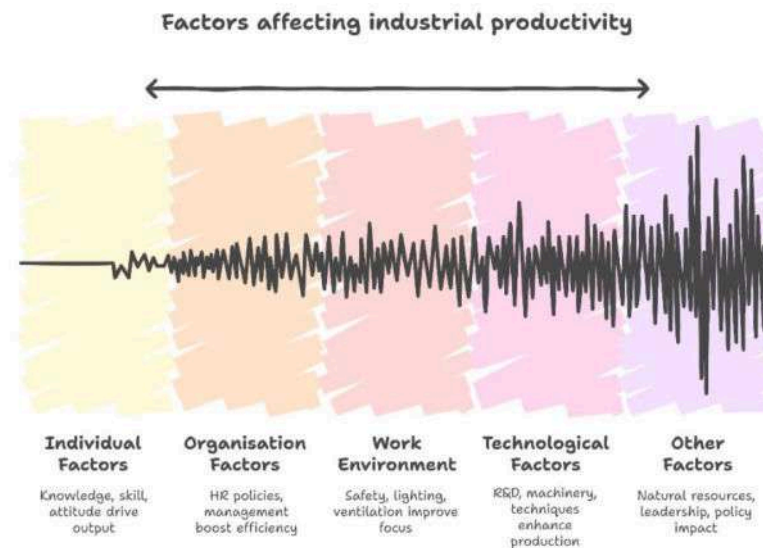
Area	Focus	Goal
Human Aspects	Empower workers, improve relationships	Motivation + collaboration
Supply of Inputs	Upgrade materials and machines	Better quality + efficiency
Technological Tools	Optimize processes and systems	Speed + consistency + control

Final Thought

	Improving Productivity
1.	Essence Improving productivity is a team effort.
2.	Requirements ✓ Smart planning ✓ Use of modern tools ✓ Building a culture of continuous improvement
3.	Applicability Works across factories, service centers, or startups.
4.	Outcome These tools act as a roadmap to excellence.

Concept Book: Factors Affecting Industrial Productivity

✦ Productivity is not just a result—it's a reflection of everything that goes into making it happen.



1. Technological Development

Productivity is shaped by how well technology supports both **output generation** and **input efficiency**.

	Content
1.	Size of the Plant Too large or too small → inefficiencies in space, cost, and coordination
2.	Research & Development Better methods, designs, and quality → higher output with same input
3.	Plant & Job Layout Smart arrangement of machines and workers → faster production, lower cost
4.	Machine Design Modern, ergonomic equipment → smoother operations and less fatigue
5.	Production Processes Automation and semi-processed inputs → speed and consistency
6.	Power & Raw Materials High-quality inputs and efficient energy use → fewer defects, more output
7.	Scientific Management Time-motion studies, waste reduction, planning → streamlined operations
8.	Capital & Environment Investment and economic stability → better tools and motivated workforce
	Example: A company upgrades to automated packaging machines and sees a 25% increase in daily output.

2. Individual Factors

The **human element** is central to productivity.

	Content
1.	Knowledge Education, training, and curiosity → smarter work methods
2.	Skill Experience, aptitude, and training → higher precision and speed
3.	Attitude Positive mindset → better teamwork and commitment
4.	Motivation Driven by leadership, recognition, and purpose → sustained effort
5.	Example: A motivated team with regular skill workshops consistently meets production targets ahead of schedule.

3. Organizational Factors

The **structure and culture** of the organization directly influence productivity.

	Content
1.	Industrial Relations Delegation, decentralization, and worker participation → smoother operations
2.	Organizational Efficiency Smart HR policies, incentives, and communication → better coordination
3.	Motivational Influence Shared goals and team spirit → collective productivity boost
4.	Hawthorne Experiments Showed that motivated workers perform better when they feel valued

4. Work Environment

A healthy and supportive environment enhances both **physical and mental performance**.

	Content
1.	Physical Conditions Ventilation, lighting, safety, noise control → comfort and focus
2.	Psychological Factors Job satisfaction, mental well-being → reduced stress and absenteeism
	Example: A factory with ergonomic workstations and natural lighting reports fewer errors and higher morale.

Other Influencing Factors of Productivity

a)	Natural Factors Geography & Climate: Access to natural resources and favorable climate raise

	productivity.
b)	Managerial Factors ✓ Leadership & Decision-Making: Good managers optimize resources and inspire teams. ✓ Entrepreneurship: Strategic thinking and innovation drive growth.
c)	Government Policy ✓ Taxation, Tariffs, Incentives: Supportive policies cut costs & promote expansion. Example: Solar subsidies reduce energy costs → industries increase output.

Key Takeaways

Category	Focus Area	Impact on Productivity
Technological	Machines, layout, R&D	Efficiency and speed
Individual	Skills, attitude, motivation	Quality and consistency
Organizational	Structure, policies, culture	Coordination and morale
Environmental	Physical and psychological conditions	Comfort and performance
External	Natural, managerial, and policy factors	Strategic advantage

Concept Book: Production vs Productivity

What is Production?	
1.	Definition The volume, value, or quantity of goods and services produced within a specific time period by a worker, plant, firm, or economy.
2.	Key Points ✓ Focuses on total output ✓ Measures how much is produced ✓ Involves factors of production (labour, capital, materials, machinery, etc.)
3.	Example A factory produces 10,000 furniture units in a month → this is its production volume.

What is Productivity?

Productivity	
1.	Definition Productivity is the ratio of output to input, showing how efficiently resources are used to produce goods or services.
2.	Key Points ✓ Focuses on efficiency, not quantity ✓ Measures output per unit of input ✓ Indicates performance level of input factors
3.	Example A factory uses 1,000 man-hours to produce 10,000 units. $\text{Productivity} = 10,000 \div 1,000 = 10 \text{ units/hour}$

Difference Between Production & Productivity

Aspect	Production	Productivity
Meaning	Total output	Efficiency of input usage

Measurement	Absolute quantity	Relative ratio (output/input)
Focus	"How much is produced?"	"How well is it produced?"
Input Sensitivity	May increase with more inputs	May remain constant or decline if inputs rise equally
Example	Producing 10,000 units	Producing 10 units per man-hour

	Important Insight
1.	Core Idea An increase in production ≠ always an increase in productivity .
2.	Example A company raises output from 10,000 → 20,000 units , but also doubles workforce & resources . ✓ Productivity stays the same ✓ No efficiency gain.

	 Key Takeaways
1.	Production Measures total output
2.	Productivity Measures efficiency of inputs
3.	Relationship More production ≠ more productivity
4.	Strategic Value Productivity helps identify cost-saving and performance-improving opportunities

2. Five Key Aspects of Productivity

	Five Key Aspects of Productivity A Concept Book for Learners, Managers & Strategists
	Understanding Productivity ✓ Definition: Ratio of output to input , showing how efficiently resources are used. Formula: Productivity = Output / Input or Results / Time ✓ "Productivity is getting important things done consistently." " - James Clear ✓ Example: Carpenter A completes a task in 5 hrs , Carpenter B in 10 hrs → A is twice as productive .
	Inputs & Outputs ✓ Inputs: Land, Workforce, Materials, Facilities, Capital, Technology, Tools. ✓ Outputs: Goods & Services delivered to customer. ✓ System Concept: Inputs → transformation process → Outputs. ✓ Example: Cotton (input) → Garments (output) in a textile factory.

1.	Aspect 1: Employee Productivity ✓ Definition: Work produced by an employee in a given time. ✓ Measured by: Goal achievement, Quality, Volume of work. ✓ Improvement Strategies: Better workplace conditions, flexible schedules, clear deadlines, promote wellness, optimize meetings, coach on priorities, teach time management, recognize achievements.
2.	Aspect 2: Material Productivity ✓ Significance: Materials = 50-70% of output value. Formula: $\text{Material Productivity} = \frac{\text{Material Output (Net Sales)}}{\text{Material Input}}$. ✓ Interpretation: Index < 100 → Low; Index > 100 → Improved. ✓ Example: Spend ₹1 Cr on materials → Net Sales ₹1.5 Cr → Ratio = 150 (improved from base 100).
3.	Aspect 3: Management as Catalyst ✓ Core Insight: Land, labour, capital yield results only when organized by management. ✓ Key Points: Good managers = high results; Poor managers = waste. ✓ Managers build ability & willingness to work, align technology with skills. ✓ "The Manager is the dynamic, life-giving element in every business." – P.F. Drucker. ✓ Example: Advanced machinery under poor supervision underperforms vs. modest setup with skilled leadership.
4.	Aspect 4: Influencing Factors ✓ Technological: Product design, Layout, Capacity, Location, Raw material supply, Maintenance, Handling, R&D, Inventory control. ✓ Natural: Climate, Geography, Geology. ✓ Social: Culture, Traditions, Work norms. ✓ Political: Stability, Law & Order, Tariffs, Taxes. ✓ Economic: Market size, Banking, Credit, Transport, Communication.
5.	Aspect 5: Improvement Techniques ✓ Organizational: Set KPIs, focus on bottlenecks, invite team ideas, benchmark, re-examine workflows, set realistic goals, reward contributions, track results. ✓ Managerial: Time management, take breaks, set deadlines, avoid multitasking, apply 2-Minute Rule, skip unnecessary meetings, use bonus time for micro-tasks.

3. TQM Basic Tools and Certification

Total Quality Management (TQM)

	What is TQM?
1.	Definition A philosophy where everyone in the organisation works for continuous improvement and customer satisfaction.

"Quality is not an act, it is a habit."

- Aristotle

2. Basic Concepts

1. **Top Management Commitment** - Leadership drives quality culture.
2. **Focus on Customers** - Both internal & external.
3. **Employee Involvement** - Empowered teams solve problems.
4. **Continuous Improvement (Kaizen)** - Small changes → big results.
5. **Supplier Partnership** - Quality starts at the source.
6. **Performance Measures** - What gets measured gets improved.

Example: Toyota's **Kaizen** empowers workers to suggest daily improvements → world-class efficiency.

3. Essentials of TQM Focus

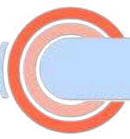
- ✓ Customer Satisfaction
- ✓ Leadership
- ✓ Quality Policy
- ✓ Organisation Structure
- ✓ Employee Involvement
- ✓ Quality Costs
- ✓ Supplier Development
- ✓ Recognition & Reward

Example: Motorola's **Six Sigma** reduced defects & boosted customer satisfaction.

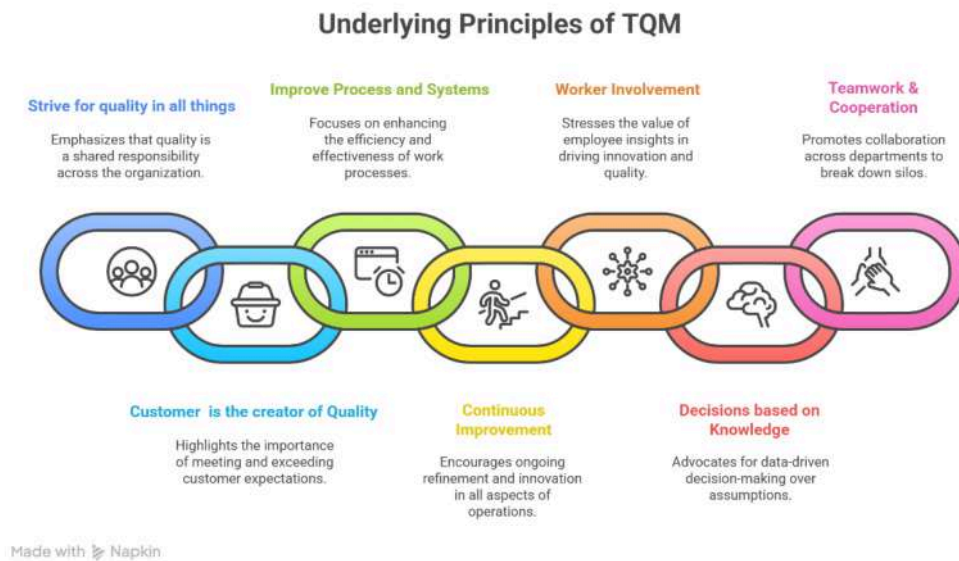
AB Mnemonic: "CLIQUE-SR"

Each letter stands for a key element:

Letter	Stands For	Description
C	Customer Satisfaction	Meeting or exceeding customer expectations
L	Leadership	Top management commitment and guidance
I	Involvement (Employee)	Empowering employees at all levels
Q	Quality Policy	Clear organizational commitment to quality
U	Organisation Structure	Defined roles and responsibilities
E	Evaluation of Quality Costs	Measuring and managing cost of quality
S	Supplier Selection & Development	Building quality partnerships with vendors
R	Recognition & Reward	Motivating employees through appreciation



Underlying Principles of TQM



	☑ Underlying Principles of TQM
1.	Strive for Quality in All Things Quality is everyone's responsibility .
2.	Customer is the Creator of Quality Customer expectations define success.
3.	Improve Processes & Systems Focus on how work is done , not just outcomes.
4.	Continuous Improvement (Kaizen) Never settle—always refine & improve .
5.	Worker Involvement Frontline insights drive innovation.
6.	Decisions Based on Knowledge Rely on data , not assumptions.
7.	Teamwork & Cooperation Cross-functional collaboration removes silos.

📌 Mnemonic: "SCI-WIDE"

Each letter stands for a core principle:

Letter	Principle	Description
S	Strive for Quality in All Things	Quality is everyone's responsibility
C	Customer is the Creator of Quality	Customer expectations define success
I	Improve Processes & Systems	Focus on how work is done
W	Worker Involvement is Essential	Frontline insights drive innovation
I	Improvement is Continuous (Kaizen)	Never settle—always refine
D	Decisions Based on Knowledge	Use data, not assumptions
E	Encourage Teamwork & Cooperation	Collaboration breaks silos

Scope of TQM	
1.	Core Idea TQM is not just tools —it is a culture .
2.	Includes ✓ Integrated Infrastructure ✓ Management Practices ✓ Tools & Techniques
3.	Example Tools ✓ Flow Charts ✓ Check Sheets ✓ Histograms ✓ Pareto Analysis ✓ Scatter Diagrams
Japanese Roots of TQM	
1.	Three Underlying Philosophies ✓ Continuous Improvement (Kaizen) ✓ Employee Involvement ✓ Customer Satisfaction
2.	Strategies ✓ Benchmarking world-class standards ✓ Supplier integration into quality programs
3.	Example Ford, GM, Motorola built long-term supplier partnerships → ensured consistent quality.
🔗 TQM vs Productivity Management	
1.	Productivity Management Focus: Efficiency (doing things faster, cheaper).
2.	TQM (Quality Management) Focus: Excellence (ensuring efficiency doesn't reduce quality).
3.	Together Create a high-performance organisation .
🧠 Final Thought	
1.	Essence ✓ TQM is not a checklist, it is a mindset → transforms organisational culture. ✓ Aligns every process and person toward quality + customer satisfaction. ✓ "Quality means doing it right when no one is looking." - Henry Ford

4. ISO Standard Basics

ISO 9000 vs. ISO 14000

What is ISO 9000?

It pertains to quality management, ensuring products/services meet customer expectations.

What is ISO 14000?

It concerns minimizing harmful environmental effects from operations.

What do they have in common?

Both relate to organizational processes and stress continual improvement.

What does the certification process involve?

Documenting worker functions, installing mechanisms for compliance, and a complex analysis of management systems.



Made with  Napkin

Quality Certification

1. Introduction to ISO

- ✓ Established in 1987 by the EU.
- ✓ ISO = International Organisation for Standardisation.
- ✓ Two key certifications:
 - ISO 9000 - Quality Management
 - ISO 14000 - Environmental Impact Reduction
 - Both focus on organisational processes, not just products.
 - Emphasize continual improvement.



2. **Global Adoption & Purpose**
 - ✓ ISO 9000 developed by 91 countries' standard bodies.
 - ✓ Adopted by ~90 countries as national standards.
 - ✓ Promotes quality at every organisational level.
3. **ISO Certification Process**
 - ✓ Elaborate & costly.
 - ✓ Requires documentation of all quality-related functions.
 - ✓ Firms must install compliance mechanisms. Steps:
 - Complex analysis of management systems
 - Evaluation of full manufacturing process (purchasing → training)
 - Independent audit & certification
 - Registration in ISO directory (favoured by global buyers)

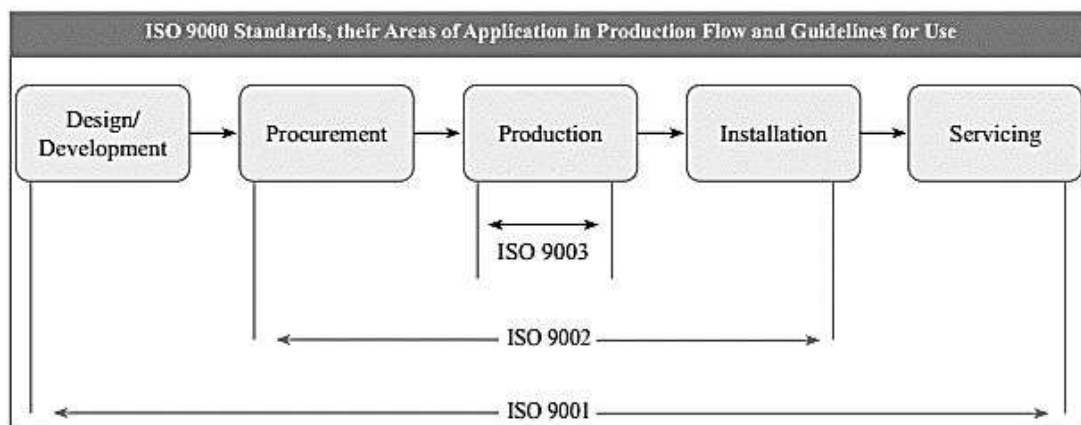
Note: ISO 9000 does not judge product quality—it evaluates quality management systems.

ISO 9000 Series - Standards Overview

Standard	Application Area	Description
ISO 9001	Design, Production, Installation, Servicing	Assures conformance during multiple stages
ISO 9002	Production & Installation	Assures conformance during production & installation
ISO 9003	Final Inspection & Test	Assures conformance only at final inspection
ISO 9000	Guidelines for Selection & Use	General quality management guidance
ISO 9004	Guidelines for Operation	Quality system elements guidance

These standards cover the entire production flow:

Design → Procurement → Production → Installation → Servicing



Strategic Importance of ISO Certification

- Mandatory for doing business with EU members
- Useful for firms without quality systems
- Provides a structured framework for setting up & improving quality management

Eight Quality Management Principles (ISO 9001:2015)

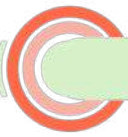
1. System Approach to Management
2. Continual Improvement
3. Factual Decision Making
4. Mutually Beneficial Supplier Relations
5. Customer Focus
6. Leadership
7. People Involvement
8. Process Approach

 **Latest Version: ISO 9001:2015 (effective Sept 2018)**

 ISO standards are reviewed every 5 years

 **Example: ISO 9001 Certification Process**

- Document department-wise contribution to quality
- Train employees on SOPs
- Audit by certified professionals
- Once approved → Listed in ISO directory, attracting global clients



MODULE 6. PROJECT MANAGEMENT, MONITORING AND CONTROL

1. Project Planning

Project Management & Planning Tools

A Concept Note for Professionals & Students

Concept	Definition	Key Points	Example
1. Project Management	Organizing and managing resources to finish a project within scope, time, cost, quality limits.	✓ Balances scope, time, cost, quality ✓ Involves planning, execution, and monitoring	Launching a mobile app : define scope, set budget, assign developers, track progress.
2. Network Analysis	Technique to plan, schedule, control complex projects by mapping activities & dependencies .	✓ Activities run sequentially or simultaneously ✓ Identifies delays, resource limits, cost impacts ✓ Uses nodes (tasks) & edges (links)	In construction , foundation must finish before framing—shown in network diagram .
3. Critical Path Method (CPM)	Identifies the longest path of dependent tasks to find minimum project duration .	✓ Critical Path: tasks with zero float ✓ Float: delay allowed without affecting project ✓ Focus on time-cost trade-offs	If $A \rightarrow B \rightarrow C = 20$ days , this is the critical path ; any delay delays the project.
4. PERT (Program Evaluation Review Technique)	A statistical tool for scheduling with uncertainty .	✓ Uses 3 estimates: Optimistic (to), Most Likely (tm), Pessimistic (tp) ✓ Expected Time: $t_e = (to + tp + 4tm)/6$ ✓ Best for R&D, innovation projects	R&D project time estimated with PERT formula to manage uncertainty.
5. Gantt Chart	A visual tool showing tasks over time with horizontal bars .	✓ Time: left $\rightarrow$ right ✓ Tasks: top $\rightarrow$ bottom	Marketing campaign : research, design, launch, review shown in timeline bars.

		✓ Shows duration, progress, dependencies ✓ Types: Work Schedule, Load Chart	
6. Activity	A task in a project that consumes time & resources.	✓ Physically identifiable ✓ Arrow in diagrams ✓ Dependent on predecessors	Laying a pipeline = activity; must wait for prior tasks.

Concept	Definition / Meaning	Key Points / Formula	Example / Representation
1. Activity Relationships	Show how activities are connected.	✓ Predecessor Activity → must finish before another starts ✓ Successor Activity → starts after a preceding one ✓ Concurrent Activities → run simultaneously	Construction: Foundation (predecessor) → Framing (successor)
2. Dummy Activity	A task with no time or resources, used for proper documentation and sequencing.	✓ Maintains precedence relationships ✓ Differentiates activities with same start/end ✓ Dashed arrow in network diagram	If C depends on B and D depends on A & B, insert a dummy to represent dependency.
3. Event	A point marking the start or end of activities.	✓ Tail Event → activity begins (e.g., event 2 in "2→3") ✓ Head Event → activity ends ✓ Predecessor Event → occurs earlier ✓ Successor Event → follows later	In activity 2→3: event 2 = Tail, event 3 = Head

4. Time Terminologies	Used to calculate project schedule.	✓ Earliest Event Time (EET) → earliest an event can occur (E2) ✓ Latest Event Time (LET) → latest an event can occur (L2) ✓ Earliest Start Time (EST) = event's EET ✓ Earliest Finish Time (EFT) = EST + Duration ✓ Latest Finish Time (LFT) = last finish w/out delay ✓ Latest Start Time (LST) = LFT - Duration	For activity 2→3: EST = E2 EFT = EST + duration LST = LFT - duration
5. Float Terminologies	Show how long activities can be delayed.	✓ Total Float (TF) = LFT - EFT or LST - EST ✓ Free Float (FF) = E3 - E2 - Duration ✓ Independent Float (IF) = E3 - L2 - Duration	If activity 2→3 has slack, TF/FF/IF measure the delay allowance.
6. Critical Path	The longest sequence of dependent activities → determines project duration.	✓ No float/slack ✓ Delaying any task on it delays the whole project	In multiple paths, the one taking longest duration is the critical path.

2. Event Types in Network Diagrams

Concept	Definition / Meaning	Key Points	Example
🔗 Merge Event	Event where multiple activities end at one point.	✓ Convergence point of tasks	Nodes 3 & 4 both ending activities.
🔗 Burst Event	Event where multiple activities start from one point.	✓ Divergence point of tasks	Nodes 1 & 2 both starting activities.
🔗 Merge & Burst Event	Event where many activities end and many begin .	✓ Combination of merge + burst	One node acts as both an end and start for different tasks.
🕒 Critical Path Method (CPM)	A planning & scheduling tool that finds the longest path of activities.	✓ Based on deterministic (fixed) time estimates ✓ Identifies critical activities needing priority ✓ Ensures resource optimization	In construction , foundation → framing → roofing may form the critical path . Any delay here delays the whole project .

 Program Evaluation and Review Technique (PERT)

📊 Concept	Definition / Meaning	Key Points	Example / Use
♀ PERT (Program Evaluation Review Technique)	A time-event network analysis tool for uncertain project scheduling.	✓ Developed by U.S. Navy (1958) ✓ Uses probabilistic time estimates (optimistic, most likely, pessimistic) ✓ Best for large, complex projects with uncertainty	Applied in defense, chemical plants, construction, and R&D projects with uncertain timelines.

 Major Features of PERT

Concept	Definition / Meaning	Representation
Network Diagram Basics	A graphical representation of the project showing tasks and their dependencies.	✓ Events → shown as circles , mark milestones (completion points) ✓ Activities → shown as arrows , represent time-consuming tasks between events ✓ The entire project is visualized as a network of events + activities

Activity Time Estimates

PERT uses **three time estimates** to calculate expected duration:

Estimate Type	Symbol	Description
Optimistic Time	t_o	Best-case scenario
Most Likely Time	t_m	Typical duration based on experience
Pessimistic Time	t_p	Worst-case scenario under adverse conditions

Concept	Definition / Meaning	Formula / Key Point	Example
Expected Time (t_e)	Average duration of an activity considering uncertainty.	$t_e = (t_o + 4t_m + t_p) / 6$ t_o = Optimistic t_m = Most likely t_p = Pessimistic	If $t_o=4$, $t_m=6$, $t_p=10 \rightarrow$ $t_e = (4+24+10)/6 = 6.33$ days
Standard Deviation (σ)	Measures uncertainty/variability in activity duration.	$\sqrt{\sum \left(\frac{t_p - t_o}{6} \right)^2}$	If $t_o=4$, $t_p=10 \rightarrow \sigma = 1$; Variance = $1^2 = 1$
Critical Path	Longest sequence of dependent activities.	✓ Determines minimum project duration ✓ Activities on it have zero slack	Path A→B→C = 30 days → critical path
Slack Time (Float)	Delay allowed in an activity without delaying the project.	Slack = Critical Path Duration - Other Path Duration	Path A→B→C = 30 days Path D→E→F = 25 days → 5 days slack

CPM vs PERT - Quick Comparison

Feature	CPM	PERT
Time Estimates	Deterministic	Probabilistic (3 estimates)
Focus	Time & Cost Optimization	Time Uncertainty Management
Application	Repetitive Projects	Research & Development
Critical Path	Based on fixed durations	Based on expected durations

PERT vs CPM

Overview

Both PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are essential tools in project management.

They help in planning, scheduling, and controlling complex projects—but differ in approach, application, and analysis.

 Comparative Table: PERT vs CPM

PERT vs CPM Comparison

Aspect	PERT	CPM
Time Estimates	Three estimates	Single estimate
Focus	Events	Activities
Project Type	Non-repetitive	Repetitive
Statistical Analysis	Can be analyzed	Cannot be analyzed
Time-Cost Relationship	Does not establish	Establishes
Application Areas	R&D, defense, innovation	Civil, manufacturing, maintenance

Aspect	PERT	CPM
Time Estimates	✓ Uses three time estimates: Optimistic, Pessimistic, Most Likely	✓ Uses single time estimate for each task
Focus	✓ Concerned with events (start/end points of operations)	✓ Concerned with activities (time-consuming project elements)
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 time-cost relationship	✓ Establishes time-cost relationship (cost $\propto$ time)
Application Areas	✓ Ideal for research & development, defense, innovation	✓ Widely used in civil construction, manufacturing, maintenance

Method	Definition / Focus	Key Features	Example
PERT	Probabilistic tool developed by U.S. Navy	✓ Best for uncertain environments	Drug design: unpredictable stages →

	(1958) for projects with uncertain timelines.	✓ Uses probability models to estimate time ✓ Activity durations are not predictable	PERT estimates realistic completion time
CPM	Deterministic tool for projects with known activity durations and focus on time-cost efficiency.	✓ Best for routine, predictable projects ✓ Identifies critical activities to prevent delays ✓ Emphasizes efficiency & cost control	Highway construction: tasks like excavation, paving, inspection → CPM optimizes schedule & cost

Time Estimation in PERT

Concept	Definition / Meaning	Key Points	Example
Three Time Estimates (PERT)	Used to handle uncertainty in activity duration.	✓ Optimistic Time (t_o) → best-case scenario (minimum time) ✓ Most Likely Time (t_m) → realistic/typical duration ✓ Pessimistic Time (t_p) → worst-case scenario (maximum time)	For a testing phase: $t_o = 4$ days $t_m = 6$ days $t_p = 12$ days

3. Gantt Charts

Concept	Definition / Meaning	Key Points	Example
Gantt Chart	A graphical tool showing activities plotted against a time scale.	✓ X-axis → Time ✓ Y-axis → Activities ✓ Horizontal bars → show start & finish dates ✓ Also called Horizontal Bar Chart	In construction, tasks like excavation, foundation, framing, roofing are shown as bars across a timeline for easy visualization.

4. Gantt Chart Strengths

 Concept	Strengths of Gantt Charts	Why It Matters
 Ease of Use	✓ Simple to understand by all stakeholders ✓ Easy to develop & interpret	Ensures everyone (from workers to managers) can follow the plan
 Progress Tracking	✓ Shows project progress at multiple levels ✓ Useful for planning & monitoring	Keeps projects on schedule and identifies delays
 Resource Management	✓ Facilitates manpower & equipment allocation ✓ Allows changes in timing & machine loads	Optimizes use of resources throughout the project
 Flexibility of Formats	✓ Can be made on ruled paper, mechanical devices, or computer software	Works for both small teams and large modern enterprises

5. Basics of MS Project

Concept	Definition / Meaning	Key Features / Uses	Why It Matters
Microsoft Project	A project management software developed by Microsoft for planning, scheduling, and controlling projects.	✓ Develop schedules ✓ Assign resources to tasks ✓ Track progress ✓ Manage budgets ✓ Analyze workloads	Provides an integrated platform to organize tasks, timelines, and resources, making it easier to manage complex projects efficiently.

 Project Management with MS Project

Concept	Definition / Meaning	Key Considerations	Example
MS Project & Planning	MS Project creates schedules within constraints, but does not replace strategic planning.	Project managers must still consider: ✓ Scope → tasks & logical order ✓ Time → deadlines & constraints ✓ Resources → manpower, machines, materials ✓ Cost → budgeting for each task ✓ Risk → uncertainties affecting scope, cost, time	Product launch: define design, testing, marketing tasks → assign teams → set deadlines → allocate budget → track in MS Project

MODULE 7. ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

1. Breakdown Maintenance

Types of Maintenances



	Breakdown Maintenance
1.	Definition A reactive maintenance strategy where repairs are made only after a failure occurs. Typically used for non-critical equipment.
2.	Core Idea "Fix it only when it breaks."
3.	Process Flow Machine operates without checks. Breakdown happens unexpectedly. Defect is found. Spares are obtained. Repairs are done. Machine is restored.
4.	Key Drawbacks Issue
5.	Unplanned Downtime Loss of production hours

6.	Higher Repair Costs Emergency repairs are more expensive
7.	Cascading Failures One failure may cause other issues
8.	Longer Idle Time Waiting for spares and technicians

When Is It Acceptable?

Breakdown maintenance is economical for non-critical items, such as:

1.	Examples ✓ Decorative lighting in a guest house ✓ Office fans or water dispensers ✓ Backup printers in non-production areas
2.	Reasons ✓ Low repair costs ✓ Minimal impact on operations ✓ Easy replacement options

1.	Real-World Example A guest house has a non-essential ceiling fan that stops working. It is repaired only when it fails as it doesn't affect operations. However, a water pump failure disrupts guest comfort and operations, making breakdown maintenance a poor choice.
2.	Common Misconception Misconception: "We save time by avoiding scheduled maintenance."
3.	Reality: Breakdown maintenance often leads to longer downtime, higher costs, and reduced productivity.

Mnemonic	B-R-E-A-K
B	Breaks before action
R	Reactive approach
E	Emergency repairs
A	Availability suffers
K	Key risks increase

1.	Summary Breakdown maintenance is best for low-impact equipment. For critical systems, it's risky and costly. Organizations should balance the cost of downtime with the cost of scheduled maintenance.

What is Preventive Maintenance?

A system of scheduled, planned, or preventive maintenance aimed at minimizing breakdowns by:

1. **Key Actions**
 - ✓ Locating weak parts in equipment
 - ✓ Providing regular inspections and minor repairs
 - ✓ Reducing the risk of unanticipated failures

2. **Principle**
Prevention is better than cure

Purpose & Benefits

Periodic inspection of machinery uncovers conditions leading to:

1. **Issues Addressed**
 - ✓ Production breakdown
 - ✓ Harmful depreciation
2. **Varies By**
Operational needs of each plant
3. **Key Benefits**
 - ✓ Reduces unanticipated breakdowns
 - ✓ Increases equipment availability
 - ✓ Maintains optimum productive efficiency
 - ✓ Reduces maintenance workload
 - ✓ Enhances worker safety
 - ✓ Boosts overall productivity

Record Keeping & Analysis

Companies should keep records of:

1. **Essential Records**
 - ✓ Component failures
 - ✓ Maintenance costs (labour, materials, spares)
2. **Analysis Benefits**
 - ✓ Analyze failure patterns statistically
 - ✓ Replace items before failure- Evaluate cost-effectiveness of maintenance

Departmental Responsibility

Production or Maintenance Department handles preventive maintenance

1. **Dependence on Plant Size**
Depends on plant size and structure
2. **Cost Consideration**
Preventive maintenance is costly, so tracking performance and cost is essential

Advantages of Preventive Maintenance

1. **Reduced Breakdowns and Downtime**
 - ✓ Regular inspections detect issues early

	✓ Minimizes unplanned stoppages Example: Routine lubrication of conveyor belts prevents sudden halts in packaging lines.
2.	Greater Safety to Workers ✓ Well-maintained equipment reduces accident risks ✓ Ensures a safer working environment Example: Periodic checks of electrical panels prevent short circuits and fire hazards.
3.	Fewer Large-Scale Repairs ✓ Small fixes prevent major failures ✓ Saves time and cost on extensive repairs Example: Replacing worn-out bearings avoids damage to motor assemblies.
4.	Less Standby or Reserve Equipment ✓ Reliable machinery reduces the need for backup systems ✓ Optimizes inventory and capital investment Example: Well-maintained boilers reduce the need for a secondary unit on standby.
5.	Lower Unit Cost of Product Manufactured ✓ Fewer breakdowns lead to less production loss ✓ Improves cost-efficiency per unit Example: Consistent machine uptime leads to higher output with lower operational cost.
6.	Better Product Quality ✓ Stable equipment performance ensures consistent output ✓ Reduces defects and rework Example: Regularly maintained cutting tools produce uniform parts with minimal error.
7.	Increased Equipment Life ✓ Timely care extends the lifespan of machinery ✓ Delays capital expenditure on replacements Example: Scheduled cleaning of CNC machines prolongs their usability.
8.	Better Industrial Relations ✓ Smooth operations reduce stress and conflict ✓ Builds trust between management and workforce Example: Workers feel valued when safety and tools are prioritized, improving morale and cooperation.

Routine Maintenance Techniques

1.	Running Maintenance ✓ Lubrication, cleaning, and periodic overhauls ✓ Performed while equipment is running or during planned shutdowns Example: Lubricating conveyor belts during scheduled breaks to prevent wear and tear.
2.	Predictive Maintenance ✓ Definition: Uses data analytics and real-time monitoring to predict equipment failure. ✓ Maintenance is performed just before the predicted failure.

How Predictive Maintenance Works

1. **Sensors**
Track **equipment condition** continuously
2. **Software**
Analyzes data to forecast potential breakdowns
3. **Maintenance Scheduling**
Proactively scheduled based on predictions, not reactively **Example:** Sensors monitor turbine vibrations, and when abnormal patterns are detected, maintenance is scheduled to prevent failure.

Key Benefits of Predictive Maintenance

- ✓ **Reduces unexpected breakdowns**
- ✓ **Extends equipment life**
- ✓ **Improves safety and reliability**
- ✓ **Optimizes maintenance costs**

2. Spare Parts Management

Types of Spare parts



Types of Spare Parts

1. **Overview**
Spare parts are crucial for **equipment reliability**, minimizing **downtime**, and optimizing **maintenance planning**. They are categorized based on usage frequency, criticality, and cost impact.
1. **Regular Spares**
Definition: Spare parts required regularly and in substantial numbers.
Characteristics
 - ✓ **Low-cost**
 - ✓ **Moderate reliability**

	✓ Used in routine maintenance Example (Centrifugal Pump) ✓ Gaskets, seals, nuts & bolts These are replaced frequently during scheduled servicing.
2.	Rotable Spares Definition: Items of plant or assets periodically changed out for repair or overhaul. Characteristics ✓ Repaired and reused ✓ High initial cost, but cost-effective over time Example (Centrifugal Pump) ✓ Impeller, motor bearings, shaft sleeves Removed, refurbished, and rotated back into operation.
3.	Insurance Spares Definition: Spare parts kept for critical equipment where downtime costs are high. Characteristics ✓ Acts as insurance against costly failures ✓ Rarely used, but strategically important Example (Centrifugal Pump) ✓ Pump casing, motor assembly Having a spare avoids production loss if the motor fails unexpectedly.
4.	Capital Spares Definition: High-value spares integral to the capital investment in equipment. Characteristics ✓ Long lead time ✓ High cost ✓ Usually purchased during initial equipment procurement Example (Centrifugal Pump) ✓ Pump housing, drive shaft, base frame Not regularly stocked but essential for long-term asset integrity.

OPERATIONS MANAGEMENT QUESTION BANK - INDEX

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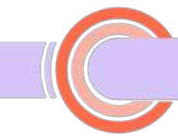
ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

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MULTIPLE CHOICE QUESTIONS

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MODULE 1. INTRODUCTION

Question 1: What is Operations Management (OM) ?

Operations management is the management of that part of an organization that is responsible for producing goods and/or services

Operations Management (OM) encompasses all organizational activities that acquire the raw form of materials (input), process or convert into a consumable products and services as required to meet the needs of the end customers.

OM deals with both tangible product and intangible services

Question 2: How does Operations Management contribute to meeting the needs of end customers?

OR

How does Operations Management contribute to meeting the needs of end customers?

Operations Management contributes to meeting the needs of end customers by ensuring that products and services are of high quality, delivered on time, and offered at a competitive price. By optimizing production processes, managing supply chains efficiently, and maintaining high standards of quality, OM helps organizations deliver value to customers. This, in turn, leads to higher customer satisfaction, repeat business, and a strong competitive advantage in the market. OM also involves continuous improvement practices, which help organizations adapt to changing customer needs and market conditions, ensuring long-term success.

Question 3: What is Operating System?**Other Possible Questions**

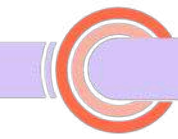
1. What is an Operating System as defined in the context of resource configuration for goods or services provision?
2. How does an Operating System convert inputs into outputs?
3. What role do physical resources play in the functioning of an Operating System?
4. How does an Operating System satisfy customer wants through its outputs?

An Operating System is defined as a configuration of resources combined for the provision of goods or services.

Any operating system converts inputs, using physical resources, to create outputs, the function of which is to satisfy customers wants

Question 4: Objectives of Operations Management**Other Possible Questions**

1. What are the Objectives of Operations Management?
2. What are the twin objectives of Operations Management?
3. How does Operations Management aim to achieve customer service?
4. What is the significance of resource utilization in Operations Management?
5. How does efficient use of resources contribute to customer satisfaction?
6. What are the consequences of inefficient resource use or inadequate customer service in an operating system?
7. Describe the three aspects of customer service in Operations Management.
8. How do specification, cost, and timing impact customer service in Operations Management?



9. Why is it important to provide goods or services with the right specification, at the right cost, and at the right time?

The twin Objectives of Operations management are

1. Customer Services
2. Resources Utilization

1. Customer Services

To provide agreed/adequate levels of customer service (and hence customer satisfaction) by providing goods or services with the right specification, at the right cost and at the right time.

2. Resources Utilization

- ❖ The second objective is to utilize resources for the satisfaction of customer wants effectively, i.e.,
- ❖ Customer service must be provided with the achievement of effective operations through efficient use of resources.
- ❖ Inefficient use of resources or inadequate customer service leads to commercial failure of an operating system.

Three Aspects of Customer Service

The three aspects of customer of customer of services

1. Specification
2. Cost
3. Timing

Question 5: What are the Four Principal Functions of Operations Management?

Short Essay Questions

1. What are the four principal functions of operations management, and why are they essential for an organization?
2. How does the manufacturing function ensure that products meet the required quality and features?
3. What are the primary and secondary considerations in transport management, and why are they important?
4. How does supply management contribute to the production process, and what are its key considerations?
5. In what ways does service management enhance customer satisfaction and loyalty?
6. Explain the roles of Specification, Cost, and Timing in operations management and how they impact the efficiency and effectiveness of operations.

Operations Management is essential for ensuring that an organization efficiently produces and delivers goods and services. The four principal functions of operations management are Manufacture, Transport, Supply, and Service. Each function is guided by primary considerations of Specification and secondary considerations of Cost and Timing.

1. Manufacture

Manufacturing involves the transformation of raw materials into finished products. The primary consideration here is **Specification**, which ensures that the products meet the required quality and features. Secondary considerations include **Cost**, which involves managing production expenses to keep them economical, and **Timing**, which ensures that products are manufactured within the required timeframe to meet market demand.



2. Transport

Transport involves the movement of goods from one location to another. Effective transport management ensures that products are delivered to the right place at the right time. The primary consideration is **Specification**, which includes ensuring that the goods are transported safely and in good condition. **Cost** is a secondary consideration, focusing on minimizing transportation expenses. **Timing** is also crucial, as delays in transport can lead to customer dissatisfaction and increased costs.

3. Supply

Supply management involves sourcing and procuring the raw materials and components needed for production. The primary consideration is **Specification**, ensuring that the materials meet the required standards and specifications. **Cost** is a secondary consideration, focusing on obtaining materials at the best possible price. **Timing** is also important, as timely procurement is essential to avoid production delays.

4. Service

Service management involves providing support and maintenance to customers after the sale of products. The primary consideration is **Specification**, ensuring that the service meets customer expectations and requirements. **Cost** is a secondary consideration, focusing on providing services efficiently and economically. **Timing** is also crucial, as timely service can enhance customer satisfaction and loyalty.

5. Specification, Cost, and Timing

- **Specification:** This involves defining the quality, features, and standards of the product or service. It ensures that the output meets customer expectations and regulatory requirements.
- **Cost:** This involves managing expenses to ensure that the operations are economical. It includes budgeting, cost control, and finding ways to reduce expenses without compromising quality.
- **Timing:** This involves ensuring that operations are completed within the required timeframe. It includes scheduling, lead time management, and ensuring timely delivery of products and services.
- **Scope of Operations Management**

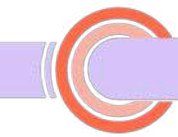


Question 6: Write a short note on Scope of Operations Management ?

Or

What is Operations Management ? and Write a short note on Scope of Operations Management

- Operations Management (OM) is a critical area of management concerned with overseeing, designing, and controlling the process of production and redesigning business operations in the production of goods or services. It involves the responsibility of ensuring that business operations are efficient in terms of using as few resources as needed and effective in meeting customer requirements. The



scope of operations management is vast and encompasses various functions, including the following eight key activities:

1. Location of Facilities

- The location of facilities is a crucial decision in operations management as it impacts the overall efficiency and effectiveness of the production process. The choice of location can affect transportation costs, access to raw materials, labour availability, and proximity to customers.
- For example, a manufacturing plant located near a major transportation hub can reduce shipping costs and improve delivery times.

2. Plant Layouts and Material Handling

- Plant layout involves the arrangement of machinery, equipment, and other industrial facilities to ensure smooth workflow and efficient production processes. Effective material handling systems are essential to minimize handling costs and reduce production time.
- For instance, an assembly line layout in an automobile manufacturing plant ensures that each component is added in a sequential manner, optimizing the production process.

3. Product Design

- Product design is the process of creating a new product to be sold by a business to its customers. It involves a thorough analysis of customer needs and market trends to develop products that meet those needs.
- For example, the design of a smartphone involves considering factors such as user interface, battery life, and camera quality to ensure it meets consumer expectations.

4. Process Design

- Process design involves planning and decision-making regarding the workflow, equipment, and technology used in the production process. It aims to create efficient processes that convert raw materials into finished products.
- For example, in a bakery, the process design would include the steps for mixing ingredients, baking, and packaging to ensure consistent quality and efficiency.

5. Production Planning and Control

- Production planning and control involve managing the production process to ensure that goods are produced on time, within budget, and to the required quality standards. This includes scheduling production runs, managing inventory levels, and coordinating with suppliers. For instance, a clothing manufacturer must plan production schedules to meet seasonal demand and ensure timely delivery to retailers.

6. Quality Control

- Quality control is the process of ensuring that products meet the required quality standards and specifications. It involves regular inspections, testing, and monitoring of production processes to identify and rectify defects.
- For example, in the pharmaceutical industry, quality control ensures that medications are produced to the highest standards of safety and efficacy.

7. Materials Management

- Materials management involves the planning, sourcing, purchasing, storing, and controlling of materials used in the production process. Effective materials management ensures that the right materials are available at the right time and in the right quantities.
- For example, a construction company must manage the procurement and storage of building materials to avoid delays and cost overruns.



8. Maintenance Management

- Maintenance management involves the upkeep of machinery, equipment, and facilities to ensure they operate efficiently and reliably. Regular maintenance helps prevent breakdowns and extends the lifespan of equipment.
- For instance, in a manufacturing plant, routine maintenance of machines ensures continuous production and reduces downtime.

Conclusion

- Operations management is a multifaceted field that plays a vital role in the success of any organization. By focusing on the eight key activities outlined above, businesses can optimize their production processes, improve efficiency, and deliver high-quality products and services to their customers. Each of these activities is interconnected and contributes to the overall effectiveness of operations management, ensuring that organizational objectives are met.

Question 7: Distinction Between Production Management and Operations Management

Understanding the differences between production management and operations management is crucial for grasping the evolution and scope of these fields. Here are two key points of distinction:

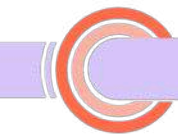
1. Tangible vs. Intangible

- **Production Management:** This term is traditionally used for systems where tangible goods are produced. For example, in a car manufacturing plant, production management focuses on the assembly of physical components like engines, chassis, and interiors to create a finished vehicle.
- **Operations Management:** This term is more frequently used in contexts where various inputs are transformed into intangible services. For instance, in a hospital, operations management involves coordinating medical staff, managing patient flow, and ensuring the availability of medical supplies to provide quality healthcare services.

2. Evolution of the Subject

- **Production Management:** Historically, production management was the predecessor to operations management. It primarily dealt with the manufacturing sector and the production of physical goods. For example, during the Industrial Revolution, production management focused on optimizing the use of machinery and labour to increase output.
- **Operations Management:** Over time, the scope expanded to include services and other non-manufacturing activities, leading to the broader term "operations management." Nowadays, operations management encompasses a wide range of activities, from managing a restaurant's kitchen operations to overseeing the logistics of an e-commerce company.
- **Characteristics of Modern Operations Function**





Modern operations functions have evolved significantly to adapt to changing market demands and technological advancements. Here are some key characteristics:

1. Manufacturing as a Competitive Advantage

- In the past, when demand was high and production capacities were limited, companies focused on maximizing output. Today, the scenario is different. With excess capacities and mounting competition, firms seek to gain a competitive edge through their production systems. Techniques like Total Quality Management (TQM), Time-Based Competition, Business Process Re-engineering (BPRE), Just-in-Time (JIT), Focused Factory, Flexible Manufacturing Systems (FMS), and Computer Integrated Manufacturing (CIM) are employed to enhance efficiency and quality.
- For example, Toyota's implementation of JIT has allowed it to reduce waste and improve production efficiency, giving it a competitive advantage in the automotive industry.

2. Service Orientation

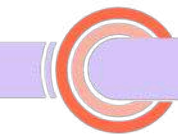
- The service sector is increasingly important in today's economy. Production systems must be organized to meet the unique requirements of services, which are often intangible and perishable. This includes constant interaction with clients, small production volumes tailored to local markets, and the strategic location of facilities.
- For instance, a hotel chain must ensure that its services are consistently high-quality and tailored to the needs of its guests, requiring efficient operations management to handle bookings, housekeeping, and customer service.

3. Disappearance of Smokestacks

- Modern factories are no longer the polluting, industrial behemoths of the past. Protective labor legislation, environmental movements, and the rise of knowledge-based organizations have transformed production systems.
- Today's factories are designed to be aesthetically pleasing and environmentally friendly, often resembling "homes away from home." For example, the Apple Park campus in Cupertino, California, is designed with sustainability in mind, featuring extensive green spaces and energy-efficient buildings.

4. Small Has Become Beautiful

- E.F. Schumacher, in his book "Small is Beautiful," advocated for smaller working units, community ownership, and regional workplaces utilizing local labor and resources. This approach opposes the trend of giant organizations and increased specialization.
- For example, many tech startups operate with small, agile teams that can quickly adapt to changes and innovate, leveraging local talent and resources to create impactful products.



Recent trends in Operations Management

Question 8: Possible Questions on Recent Trends in Operations Management

1. What are some recent trends in operations management?
2. How has globalization impacted manufacturing firms?
3. What is the importance of production/operations strategy?
4. How does Total Quality Management (TQM) contribute to customer satisfaction?
5. Why is flexibility important in modern manufacturing?
6. How does time reduction provide a competitive edge?
7. What role does technology play in operations management?
8. How does worker involvement improve organizational performance?
9. What is re-engineering and how does it benefit firms?
10. Why are environmental issues important in operations management?
11. What is corporate downsizing and why do firms implement it?
12. How does supply chain management reduce costs?
13. What is lean production and what are its benefits?

Recent Trends in Operations Management

Operations management is constantly evolving to meet the demands of a dynamic business environment. Here are some of the recent trends, along with examples to illustrate each point:

1. Global Market Place

Globalization has compelled many manufacturing firms to establish operations in multiple countries to leverage economic advantages. This has increased competition among firms worldwide.

For example, Apple manufactures its products in various countries, including China, to benefit from lower production costs and access to skilled labour.

2. Productions and Operations Strategy

Firms are increasingly recognizing the importance of aligning their production/operations strategy with their overall business strategy.

For instance, Toyota's production strategy focuses on lean manufacturing principles, which align with its business strategy of delivering high-quality vehicles efficiently.

3. Total Quality Management (TQM)

TQM is adopted by many firms to achieve customer satisfaction through continuous improvement of goods and services.

For example, Motorola implemented TQM to improve product quality, which led to significant reductions in defects and increased customer satisfaction.

4. Flexibility

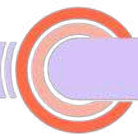
The ability to quickly adapt to changes in demand, product mix, and delivery schedules is a major competitive advantage. This is often referred to as agile manufacturing.

For example, Zara's flexible supply chain allows it to respond rapidly to changing fashion trends, keeping its inventory fresh and relevant.

5. Time Reduction

Reducing manufacturing cycle time and speeding up time-to-market for new products provide a competitive edge.

For instance, Amazon's efficient logistics and delivery systems enable it to offer same-day delivery, giving it an advantage over competitors.



6. Technology

Advances in technology have led to new products, processes, and materials. Automation, computerization, and information technologies have revolutionized operations. For example, Tesla uses advanced robotics and automation in its manufacturing processes to improve efficiency and quality.

7. Worker Involvement

Assigning decision-making and problem-solving responsibilities to lower levels in the organization, known as employee involvement and empowerment, is a growing trend.

For example, Toyota's use of quality circles allows workers to contribute to continuous improvement efforts.

8. Re-engineering

Re-engineering involves drastic measures to improve a firm's performance, often starting from scratch in redesigning business processes.

For example, Ford Motor Company re-engineered its accounts payable process, reducing the number of steps and improving efficiency.

9. Environmental Issues

Production managers are increasingly concerned with pollution control and waste disposal. There is a growing emphasis on reducing waste, recycling, and using less-toxic chemicals.

For example, Unilever has committed to reducing its environmental footprint by using sustainable materials and reducing waste.

10. Corporate Downsizing

Downsizing, or right-sizing, involves reducing the workforce to improve productivity and profitability.

For example, General Electric has undergone several rounds of downsizing to streamline operations and focus on core business areas.

11. Supply Chain Management

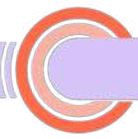
Effective supply chain management reduces costs associated with transportation, warehousing, and distribution.

For example, Walmart's efficient supply chain management practices help it maintain low prices and high availability of products.

12. Lean Production

Lean production systems use minimal resources to produce high volumes of high-quality goods. These systems employ flexible manufacturing and multi-skilled workforces.

For example, Toyota's lean production system, known as the Toyota Production System (TPS), is renowned for its efficiency and quality.



QUESTIONS FROM PYP'S

Question 1.

(Jun 24 7M)

"The Production Management of To-day presents certain characteristics which make it look totally different from what it was during the past. Specifically, To-day's production system is characterized by at least Four Features". In this Context Summarize the Said Features.

Answer:

The production management of today presents certain characteristics which make it look totally different from what it was during the past. Specifically, today's production system is characterized by at least four features.

1. Manufacturing as Competitive Advantage

In the past production was considered to be like any other function in the organization. When demand was high and production capacities were inadequate, the concern was to somehow muster all inputs and use them to produce goods which would be grabbed by market. But today's scenario is contrasting. Plants have excess capacities, competition is mounting and firms look and gain competitive advantage to survive and succeed. Interestingly, production system offers vast scope to gain competitive edge and firms intend to exploit the potential.

Total Quality Management (TQM), Time-Based Competition, Business Process Re-engineering (BPRe), Just-in-Time (JIT), Focused Factory, Flexible Manufacturing Systems (FMS), Computer Integrated Manufacturing (CIM), and The Virtual Corporation are but only some techniques which the companies are employing to gain competitive advantage.

2. Services Orientation

As was stated earlier, service sector is gaining greater relevance these days. The production system, therefore, needs to be organized keeping in mind the peculiar requirements of the service component.

The entire manufacturing needs to be geared to serve

- (i) intangible and perishable nature of the services,
- (ii) constant interaction with clients or customers,
- (iii) small volumes of production to serve local markets, and
- (iv) need to locate facilities to serve local markets.

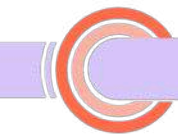
There is increased presence of professionals on the production, instead of technicians and engineers.

3. Disappearance of Smokestacks

Protective labour legislation, environmental movement and gradual emergence of knowledge based organizations have brought total transformation in the production system. Today's factories are aesthetically designed and built, environment friendly in fact, they are homes away from homes. Going to the factory everyday is no more excruciating experience, it is like holidaying at a scenic spot. A visit to ABB, L & T or Smith Kline and Beecham should convince the reader about the transformation that has taken place in the wealth creation system.

4. Small has Become Beautiful

It was E.F. Schumacher who, in his famous book Small is Beautiful, opposed giant organisations and increased specialisation. He advocated, instead, intermediate technology based on smaller working units, community ownership, and regional workplaces utilising local labour and resources. For him, small was beautiful. Businessmen, all over the world, did not believe in Schumacher's philosophy. Inspired by economies of scale, industrialists went in for huge organisations and mass production systems.

**Question 2.****(Dec 23 7M)**

"Recent trends in Production and Operation Management related to global competition and the impact it has on manufacturing firms." In this context, state in brief the recent trends in production and operations management. (Any seven)

Answer:

Recent trends in production and operations management relate to global competition and the impact it has on manufacturing firms. Some of the recent trends are:

1. Global Marketplace:

Globalisation of business has compelled many manufacturing firms to have operations in many countries where they have certain economic advantage. This has resulted in a steep increase in the level of competition among manufacturing firms throughout the world.

2. Production/Operations Strategy:

More and more firms are recognising the importance of production/ operations strategy for the overall success of their business and the necessity for relating it to their overall business strategy.

3. Total Quality Management (TQM):

The TQM approach has been adopted by many firms to achieve customer satisfaction by a never-ending quest for improving the quality of goods and services.

4. Flexibility:

The ability to adapt quickly to changes in volume of demand, in the product mix demanded, and in product design or in delivery schedules, has become a major competitive strategy and a competitive advantage to the firms. This is sometimes called agile manufacturing.

5. Time Reduction:

Reduction of manufacturing cycle time and speed to market for a new product provide competitive edge to a firm over other firms. When companies can provide products at the same price and quality, quicker delivery (short lead times) provide one firm competitive edge over the other.

6. Technology:

Advances in technology have led to a vast array of new products, new processes and new materials and components. Automation, computerisation, information and communication technologies have revolutionised the way companies operate. Technological changes in products and processes can have great impact on competitiveness and quality, if the advanced technology is carefully integrated into the existing system.

7. Worker Involvement:

The recent trend is to assign responsibility for decision making and problem solving to the lower levels in the organisation. This is known as employee involvement and empowerment. Examples of worker involvement are quality circles and use of work teams or quality improvement teams.

8. Re-engineering:

This involves drastic measures or break-through improvements to improve the performance of a firm. It involves the concept of clean-slate approach or starting from scratch in redesigning the business processes.

9. Environmental Issues:

Today's production managers are concerned more and more with pollution control and waste disposal which are key issues in protection of the environment and social responsibility. There is increasing emphasis on reducing waste, recycling waste, using less-toxic chemicals and using biodegradable materials for packaging.

**10. Corporate Downsizing (or Right Sizing):**

Downsizing or rightsizing has been forced on firms to shed their obesity. This has become necessary due to competition, lowering productivity, need for improved profit and for higher dividend payment to shareholders.

11. Supply-Chain Management:

Management of supply-chain, from suppliers to final customers reduces the cost of transportation, warehousing and distribution throughout the supply chain.

12. Lean Production:

Production systems have become lean production systems which use minimal amounts of resources to produce a high volume of high quality goods with some variety. These systems use flexible manufacturing systems and multi-skilled workforce to have advantages of both mass production and job production (or craft production).

Note: Write any seven points from the above

Question 3.**(Dec 23 4M)**

In context with today's modern operations function, list down various techniques which companies are employing to gain competitive advantage.

Answer:

Interestingly, the production system offers vast scope to gain competitive edge and firms intend to exploit the potential.

- Total Quality Management (TQM),
- Time-Based Competition,
- Business Process Re-engineering (BPRE),
- Just-in-Time (IT),
- Focused Factory,
- Flexible Manufacturing Systems (FMS),
- Computer Integrated Manufacturing (CIM), and
- The Virtual Corporation are but only some techniques which the companies are employing to gain competitive advantage.

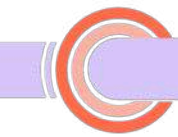
Question 4.**(Dec 23 4M)**

"Three aspects of Customer Service Specification, cost and timing are described in a little more detail for four functions". In this context summarize the Principal Customer wants

Answer:

Aspects of Customer Service

Principal Function	Primary Consideration	Other Consideration
Manufacture	Goods of a given, requested or acceptable specification	Cost i.e. purchase price or cost of obtaining goods Timing, i.e. delivery delay from order or request to receipt of goods
Transport	Movement of a given, requested or acceptable specification	Cost, i.e. cost of movement, timing, i.e. i) duration or time to move ii) wait, or delay from requesting to its commencement
Supply	Goods of a given, requested or acceptable specification	Cost, that is purchase price or cost of obtaining goods timing, i.e. delivery delay



		from order or request to supply, to receipt of goods
Service	Treatment of a given, requested or acceptable specification	Cost, i.e. cost of treatment timing, i.e. i) Duration or timing required for treatment ii) Wait, or delay from requesting to its commencement

Question 5.**(Jun 23 8M)**

"Today's production system is characterised by at least four features". In this context, enumerate in detail, what are the said features.

Answer:

The production management of today presents certain characteristics which make it look totally different from what it was during the past. Specifically, today's production system is characterised by at least four features

1. Manufacturing as Competitive Advantage

In the past production was considered to be like any other function in the organisation. When demand was high and production capacities were inadequate, the concern was to somehow muster all inputs and use them to produce goods which would be grabbed by market. But today's scenario is contrasting. Plants have excess capacities, competition is mounting and firms look and gain competitive advantage to survive and succeed. Interestingly, production system offers vast scope to gain competitive edge and firms intend to exploit the potential. Total Quality Management (TQM), Time-Based Competition, Business Process Reengineering (BPRE), Just-in-Time (JIT), Focused Factory, Flexible Manufacturing Systems (FMS), Computer Integrated Manufacturing (CIM), and The Virtual Corporation are but only some techniques which the companies are employing to gain competitive advantage.

2. Services Orientation

As was stated earlier, service sector is gaining greater relevance these days. The production system, therefore, needs to be organised keeping in mind the peculiar requirements of the service component. The entire manufacturing needs to be geared to serve (i) intangible and perishable nature of the services,

- (ii) constant interaction with clients or customers,
- (iii) small volumes of production to serve local markets, and
- (iv) need to locate facilities to serve local markets.

There is an increased presence of professionals on the production, instead of technicians and engineers.

3. Disappearance of Smokestacks

Protective labour legislation, environmental movement and gradual emergence of knowledge based organisations have brought total transformation in the production system. Today's factories are aesthetically designed and built, environment friendly - in fact, they are homes away from homes. Going to the factory everyday is no more excruciating experience, it is like holidaying at a scenic spot. A visit to ABB, L & T or Smith Kline and Beecham should convince the reader about the transformation that has taken place in the wealth creation system.

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increased specialisation. He advocated, instead, intermediate technology based on smaller working units, community ownership, and regional workplaces utilizing local labour and resources. For him, small was beautiful. Businessmen, all over the world, did not believe in Schumacher's philosophy. Inspired by economies of scale, industrialists went in for huge organisations and mass production systems.

Question 6.**(Jun 23 5M)**

List down various major decision areas under Production and Operations management. (Any Ten)

Answer:

Product Selection

- Facility Location Selection
- Demand Forecasting
- Process Selection & Layout Decision
- Capacity Planning
- Aggregate Planning, Master production schedule
- Materials Requirement Planning (MRP) / Manufacturing Resource Plan (MRPI) / Distribution Resource Planning (DRP) / Enterprise Resource Plant (ERP)
- Inventory Management
- Supplier Section/ Sourcing
- Process Management
- Quality Management
- Maintenance
- Warehousing / Transportation
- Reverse Logistics

In Addition, an operations manager is also responsible for working capital management, skill Management

Etc.

Question 7.**(Dec 22 4M)**

Enumerate what are the Activities which are listed under the production and Operations Management functions

Answer:

The following are the activities which are listed under Production and Operations Management functions



1. Location of Facilities
2. Plant Layout & Material Handling
3. Product Design
4. Process Design
5. Production Planning and Control
6. Quality Control.
7. Materials Management.
8. Maintenance Management

Question 8.**(Dec 22 4M)**

Recent trends in production/operations management relate to *Global Competition* and the impact it has on manufacturing firms. In this context list down what are the recent trends in production/operations management

Answer:

Recent trends in Production/Operations Management:

1. Global Marketplace
2. Production/Operations Strategy
3. Total Quality Management (TQM)
4. Flexibility
5. Time Reduction
6. Technology
7. Worker Involvement
8. Re-Engineering
9. Environmental Issues
10. Corporate Downsizing (or Right Sizing)
11. Supply-Chain Management
12. Lean Production

MODULE 2. OPERATIONS PLANNING

2.1 Demand Forecasting

Questions For Classroom Discussion

Question 1

Following are the details of amount spend on advertising and estimated sales.

Year	Advertisement	Sales
2012	25	254
2013	32	306
2014	44	410
2015	52	452
2016	60	528
2017	75	664

Question 2

- ◆ Write down, the regression equation y on x ?
- ◆ Write down, the regression equation x on y ?
- ◆ What is the estimated sales when amount spend on advertising is 90 ?
- ◆ What is the amount to be spend to generate a sale of 1000?

Question 3

Previous Year Question

It is observed that there exists a relationship between Expenditure on Advertising and the Annual Sales. The details for last six years are as follows :

Year	Advertisement	Sales
2004	1	18
2005	2	23
2006	4	32
2007	3	28
2008	10	38
2009	4	29

Estimate the annual Sales when Expenditure on Advertising is 5 crores?

Question 4

Previous Year Question

The following is the demand for Product A in 5 towns :

Population (In Lakhs)	Demand (1000)
9	12
5	20
8	15
5	10
3	5

Estimate the demand for Product A for a town with a population of 10 Lakhs?

Time Series Model

Question 5

Previous Year Question

From the following time series data of sales of Refrigerators, project the sales for the year 2010

Year	Sales
2002	90
2003	100
2004	102
2005	93
2006	104
2007	109
2008	102

Question 6

Previous Year Question

With the help of the following data, project the trend of sales for the next 5 years

Year	Sales
2002	120
2003	130
2004	135
2005	140
2006	150
2007	165

Direct Method

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

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

If the number of years is ODD (5 Year, 7 year, 9 year)

Question 7

Previous Year Question

For Question No. 6, we are using the direct method. This is the same question we have previously solved as Question No. 4.

From the following time series data of sales of Refrigerators, project the sales for the year 2010

Year	Sales
2002	90
2003	1000
2004	102
2005	93
2006	104
2007	109
2008	102

If the number of years is EVEN (4Year, 6year, 8 Year....)

With the help of the following data, project the trend of sales for the next 5 years

Year	Sales
2002	120
2003	130
2004	135



2005	140
2006	150
2007	165

Illustration From Study Material

Illustration 1:

From the following time series data of sale project the sales for the next three years.

Year	2017	2018	2019	2020	2021	2022	2023
Sales (Rs.000 units)	80	90	92	83	94	99	92

Answer

Computation of Trend Values

Years	Time Deviation from 2020 X	Sales in (Rs. 000 units) Y	Squares of time dev. X^2	Product of time deviations and sales XY
2017	-3	80	9	-240
2018	-2	90	4	-180
2019	-1	92	1	-92
2020	0	83	0	0
2021	+1	94	1	+94
2022	+2	99	4	+198
2023	+3	92	9	+276
n = 7	$\Sigma X = 0$	$\Sigma Y = 630$	$\Sigma X^2 = 28$	$\Sigma XY = +56$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b

$$a = \frac{\Sigma Y}{n} = \frac{630}{7} = 90$$

$$b = \frac{\Sigma XY}{\Sigma X^2} = \frac{56}{28} = 2$$

Hence regression equation comes to $Y = 90 + 2X$. With the help of this equation we can project the trend values for the next three years, i.e. 2024, 2025 and 2026.

$$Y_{2024} = 90 + 2(4) = 90 + 8 = 98 \text{ (000) units.}$$

$$Y_{2025} = 90 + 2(5) = 90 + 10 = 100 \text{ (000) units.}$$

$$Y_{2026} = 90 + 2(6) = 90 + 12 = 102 \text{ (000) units.}$$

Illustration 2:

With the help of following data project the trend of sales for the next five years:

Years	2016	2017	2018	2019	2020	2021
Sales (in lakhs)	100	110	115	120	135	140

Answer

Computation of trend values of sales

Year	Time deviations from the middle of 2016 and 2017 assuming 6 months = 1 unit	Sales (in lakh Rs.)	Squares of time deviation	Product of time deviation and sales
	X	Y	X^2	XY

2016	-5	100	25	-500
2017	-3	110	9	-330
2018	-1	115	1	-115
2019	+1	120	1	+120
2020	+3	135	9	+405
2021	+5	140	25	+700
n = 6	$\Sigma X = 0$	$\Sigma Y = 720$	$\Sigma X^2 = 70$	$\Sigma XY = 280$

Regression equation of Y on X:

$$Y = a + bX$$

To find the values of a and b

$$a = \frac{\Sigma Y}{n} = \frac{720}{6} = 120$$

$$b = \frac{\Sigma XY}{\Sigma X^2} = \frac{280}{70} = 4$$

Hence regression equation comes to $Y = 120 + 4X$

Sales forecast for the next years, i.e., 2022-26

$$Y_{2022} = 120 + 4(+7) = 120 + 28 = \text{Rs. 148 lakhs}$$

$$Y_{2023} = 120 + 4(+9) = 120 + 36 = \text{Rs. 156 lakhs}$$

$$Y_{2024} = 120 + 4(+11) = 120 + 44 = \text{Rs. 164 lakhs.}$$

$$Y_{2025} = 120 + 4(+13) = 120 + 52 = \text{Rs. 172 lakhs.}$$

$$Y_{2026} = 120 + 4(+15) = 120 + 60 = \text{Rs. 180 lakhs.}$$

Illustration 3:

An investigation into the demand for colour TV sets in 5 towns has resulted in the following data:

Population of the town (in lakhs)	X:	5	7	8	11	14
No of TV sets demanded (in thousands)	Y:	9	13	11	15	19

Fit a linear regression of Y on X and estimate the demand for CTV sets for two towns with a population of 10 lakhs and 20 lakhs.

Answer

Computation of trend values

Population (in lakhs)	Sales of CTV (in thousands)	Squares of the population	Product of population and sales of colour TV
X	Y	X^2	XY
5	9	25	45
7	13	49	91
8	11	64	88
11	15	121	165
14	19	196	266
$\Sigma X = 45$	$\Sigma y = 67$	$\Sigma X^2 = 455$	$\Sigma XY = 655$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b, the following two equations are to be solved

$$\Sigma Y = na + b\Sigma X \quad (i)$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \quad (ii)$$

By putting the values we get

$$67 = 5a + 45b \quad \text{(iii)}$$

$$655 = 45a + 455b \quad \text{(iv)}$$

Multiplying equation (iii) by 9 and putting it as no. (v) we get,

$$603 = 45a + 405b \quad \text{(v)}$$

By deducting equation (v) from equation (iv); we get $52 = 50b$

$$b = \frac{52}{50} = 1.04$$

By putting the value of b in equation (iii), we get

$$67 = 5a + 45 \times 1.04$$

$$\text{or, } 67 = 5a + 46.80$$

$$\text{or, } 67 - 46.80 = 5a$$

$$\text{or, } 5a = 20.20$$

$$\text{or, } a = \frac{20.20}{5}$$

$$\text{or, } a = 4.04$$

Now by putting the values of a and b the required regression equation of Y on X, is

$$Y = a + bX \text{ or, } Y = 4.04 + 1.04X$$

When X = 10 lakhs then

$$Y = 4.04 + 1.04 (10)$$

$$\text{or, } Y = 4.04 + 10.40 \text{ or } 14.44 \text{ thousand CTV sets.}$$

Similarly for town having population of 20 lakhs, by putting the value of X = 20 lakhs in regression equation

$$Y = 4.04 + 1.04 (20)$$

$$= 4.04 + 20.80 = 24.84 \text{ thousands CTV sets.}$$

Hence expected demand for CTV for two towns will be 14.44 thousand and 24.84 thousand CTV sets.

Illustration 4:

An investigation into the use of scooters in 5 towns has resulted in the following data: Population in town

Population in town (in lakhs)	(X)	4	6	7	10	13
No. of scooters	(Y)	4,400	6,600	5,700	8,000	10,300

Fit a linear regression of Y on X and estimate the number of scooters to be found in a town with a population of 16 lakhs.

Answer:

Computation of trend value

Population (in lakhs) X	No. of scooters demanded Y	Squares of population X^2	Product of population and No. of scooters demanded XY
4	4,400	16	17,600
6	6,600	36	39,600
7	5,700	49	39,900
10	8,000	100	80,000
13	10,300	169	1,33,900
$\Sigma X = 40$	$\Sigma Y = 35,000$	$\Sigma X^2 = 370$	$\Sigma XY = 3,11,000$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b we will have to solve the following two equations

$$\Sigma Y = na + b\Sigma X \dots \quad (i)$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \dots \quad (ii)$$

By putting the values, we get

$$35,000 = 5a + 40b \dots \quad (iii)$$

$$3,11,000 = 40a + 370b \dots \quad (iv)$$

By multiplying equation no. (iii) by 8 putting as equation (v) we get,

$$2,80,000 = 40a + 320b \dots \quad (v)$$

By subtracting equation (v) from equation (iv), we get

$$31,000 = 50b$$

$$\text{or, } 50b = 31,000$$

$$\text{or, } b = \frac{310}{50} = 620$$

By substituting the value of b in equation no. (iii), we get

$$35,000 = 5a + 40b$$

$$\text{Or } 35,000 = 5a + 40 \times 620$$

$$\text{or } 35,000 = 5a + 24,800$$

$$\text{or } 10,200 = 5a$$

$$\text{or } a = \frac{10200}{5} = 2040$$

Now putting the values of a and b the required regression equation of Y on X, is

$$Y = a + bX \text{ or, } Y = 2040 + 620 X$$

$$\text{When } X = 16 \text{ lakhs then } Y = 2040 + 620 (16)$$

$$\text{or } Y = 2040 + 9920$$

$$\text{or } Y = 11,960$$

Hence, the expected demand of scooters for a town with a population of 16 lakhs will be 11,960 scooters.

2.2 Capacity Planning

Questions For Classroom Discussion

Question 1

A worker works for 8 hours in each shift, but during that period, he had clocked for 7 hours on the job. Calculate his utilization.

Question 2

Standard time for a task is 8 hours. Calculate the efficiency of a workman in the following cases.

- A) Worker Completes the job in 10 Hours
- B) Worker completes the job in 6 Hours
- C) Worker completes the job in 8 Hours.

Question 3

A worker is employed for 12 hours. During this period, he takes 8 hours to complete a job with a standard time of 7 hours. Calculate the productivity of the worker as a percentage.

Question 4

A department works on 8 hours shift, 250 days a year and has the usage data of a machine as given below.

Product	Annual Demand	Processing Time
X	300	4
Y	400	6
Z	500	3

Q1: What is the Annual Production capacity of one machine in Hours ?

Q2: What is the Total Processing time required to produce products X,Y,Z is

Q3: Determine Number of Machines Required?

Question 5

Home Work

A department works on 8 hours shift, 250 days a year and has the usage data of a machine, as given below:

Product	Annual Demand	Processing Time
A	600	4
B	800	6
C	1000	3

Compute

Q1) Annual Production capacity of a single machine

Q2) What is the total annual processing time required to produce products A,B,C

Q3) Determine the number of machines required ?

Question 6

A steel Plant has a design capacity of 50,000 tons of steels per day, effective capacity of 40,000 tons of steels per day and an actual output of 36,000 tons of steels per day. Compute the efficiency of the plant and its utilization.

Question 7

An item is produced in a plant having a fixed cost of Rs 6000 per month, Variable cost of Rs 2 Per unit and Selling price of Rs 7 per unit. Determine

Q1) The break even Volume

Q2) If 1000 units are produced and sold in a month, what would be the profit?

Q3) How many units should be produced to earn a profit of Rs 4000 per month.

Question 8

A manager has to decide about the number of machines to be purchased. He has three options, i.e. Purchasing one, or two or three machines. The data are given below.

Number of Machine	Annual Fixed Cost	Corresponding range of Output
One	12,000	0 to 300
Two	15,000	301 to 600
Three	21,000	601 to 900

Variable cost is Rs 20 per unit and Revenue is Rs.50 per unit.

a) Determine the Break Even point for each range.

b) If Projected demand is between 600 to 650 units, How many machines should the manager purchase?

Question 9**Previous Year Question**

A manager has to decide about the number of machines to be purchased. He has three options, i.e. Purchasing one, or two or three machines. The data are given below.

Number of Machine	Annual Fixed cost	Corresponding range of Output
One	10,000	0 to 400
Two	12,000	401 to 700
Three	20,000	701 to 1000

Variable cost is Rs 20 per unit and Revenue is Rs.40 per unit.

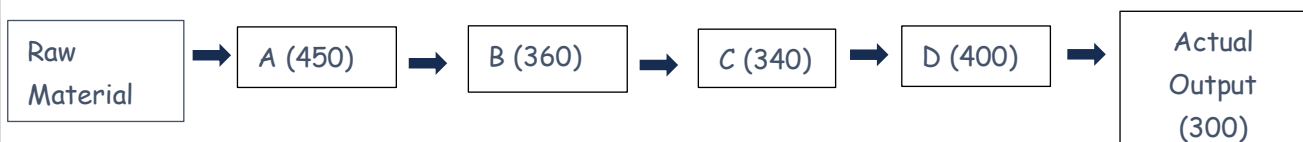
a) Determine the Break Even point for each range.

b) If Projected demand is between 700 to 750 units, How many machines should the manager purchase?

June 2010 Q3(a) , 3+2 Marks

Question 10

A firm has four work centres A,B,C, &D in series with individual capacities in units per day shown in the figure below.



Q1) Identify the bottleneck centre?

Q2) What is the system Capacity?

Q3) What is the system Efficiency?

A firm has 5 work centres A,B,C,D,E in series and Actual output of 500 units. Compute

- 1) System Capacity
- 2) Efficiency of production line

Work Station	A	B	C	D	E
Capacity/ Shift	600	650	650	550	600

Question 11

A company is planning to start an assembly unit of television sets must decide on the location of its plant at any of the three cities, viz, Kolkata, Delhi or Mumbai. The extent of fixed and variable costs for each of these locations are estimated to be as under

Locations	Kolkata	Delhi	Mumbai
Fixed cost	3,000,000	5,000,000	2,500,000
Variable Cost	300	200	350

Expected Selling Price Rs 700

- Q1) Break even point for each locations?
- Q2) The range of annual production/ Sales volume for each location is most suitable.
- Q3) Which one of the three location is best suitable for a production or sales volume of 18000 units?

Question 12

Previous Year Question

The fixed cost for the production of particular item is Rs. 200 per month. Its variable cost being Rs. 3 per unit and its sale price being Rs. 7 per unit,

- Q1) Determine its break-even volume.
- Q2) What would be the profit if 2,000 such units were sold in a month?
- Q3) How many such units should be sold to earn a profit of Rs. 3,000 per month?

Answer

- Q1) 50 Units
- Q2) Rs 7800
- Q3) 800 Units

Question 13

Previous Year Question

A company is planning to undertake the production of medical testing equipment and has to decide on the location of the plant. Two locations are being considered, namely, A and B. The fixed costs of two locations are estimated to be Rs. 25 lakhs and Rs. 30 lakhs respectively. The variable costs are Rs. 300 and Rs. 250 per unit respectively. The average sale price of the equipment is Rs. 550 per unit.

Find the range of annual production/sales volume for which each location is most suitable.

Answers

Break Even Point for

A is 10,000 and B 10,000

Since Contribution per Units from Location B is more than A, For above 10,000 units, Location B is preferred.

Illustration From Study Material

Illustration 5:

A department works on 8 hours shift, 250 days a year and has the usage data of a machine, as given below:

Product	Annual demand (units)	Processing time (standard time in hours)
X	300	4.0
Y	400	6.0
Z	500	3.0

Determine the number of machines required.

Answer

Step 1: Calculate the processing time needed in hours to produce product x, y and z in the quantities demanded using the standard time data.

Product	Annual demand (units)	Standard processing time per unit (Hrs.)	Processing time needed (Hrs.)
X	300	4.0	$300 \times 4 = 1200$ Hrs.
Y	400	6.0	$400 \times 6 = 2400$ Hrs.
Z	500	3.0	$500 \times 3 = 1500$ Hrs.
			Total = 5100 Hrs

Step 2 : Annual production capacity of one machine in standard hours = $8 \times 250 = 2000$ hours per year

Step 3 : Number of machines required

$$= \frac{\text{Work load per year}}{\text{Production capacity per machine}} = \frac{5100}{2000} = 2.55 = 3 \text{ machines}$$

Illustration 6:

A steel plant has a design capacity of 50,000 tons of steel per day, effective capacity of 40,000 tons of steel per day and an actual output of 36,000 tons of steel per day. Compute the efficiency of the plant and its utilisation.

Answer:

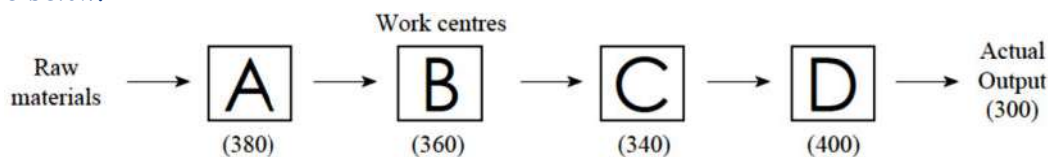
Actual output

$$\text{Efficiency of the plant} = \frac{\text{Actual output}}{\text{Effective Capacity}} = \left(\frac{36000}{40000} \right) \times 100 = 90\%$$

$$\text{Utilisation} = \left(\frac{\text{Actual output}}{\text{Design Capacity}} \right) = \left(\frac{36000}{50000} \right) \times 100 = 72\%$$

Illustration 7:

A firm has four work centres, A, B-n, C & D, in series with individual capacities in units per day shown in the figure below.



- (i) Identify the bottle neck centre.
- (ii) What is the system capacity?
- (iii) What is the system efficiency?

Answer

- (i) The bottle neck centre is the work centre having the minimum capacity. Hence, work centre 'C' is the bottleneck centre.
- (ii) System capacity is the maximum units that are possible to produce in the system as a whole. Hence, system capacity is the capacity of the bottle neck centre i.e., 340 units.
- (iii) System efficiency = $\frac{\text{Actual output}}{\text{System Capacity}} = \frac{300}{400} \times 100$ (i.e., maximum possible output) = 88.23%

Illustration 8:

A manager has to decide about the number of machines to be purchased. He has three options i.e., purchasing one, or two or three machines. The data are given below.

Number of Machine	Annual fixed cost	Corresponding range of output
One	Rs. 12,000	0 to 300
Two	Rs. 15,000	301 to 600
Three	Rs. 21,000	601 to 900

Variable cost is Rs. 20 per unit and revenue is Rs. 50 per unit

- (a) Determine the break-even point for each range
- (b) If projected demand is between 600 and 650 units how many machines should the manager purchase?

Answer

- (i) Break-even point

Let Q be the break even point.

FC = Fixed cost, R = Revenue per unit, VC = Variable cost

At, BEP, TR = FC + TVC

or, Revenue p.u $\times$ Q = FC + VCp.u. $\times$ Q

Q (R - VC) = FC

$$Q = \frac{FC}{R-VC}$$

Let Q1 be the break-even-point for one machine option

$$\text{Then, } Q1 = \frac{1200}{(50-20)} = \frac{1200}{30} = 400 \text{ units}$$

(Not within the range of 0 to 300)

Let Q2 be the break-even-point for two machines option.

$$\text{Then } Q2 = \frac{1500}{(50-20)} = \frac{1500}{30} = 500 \text{ units}$$

(within the range of 301 to 600)

Let Q3 be the break-even-point for three machines option.

$$\text{Then } Q3 = \frac{21000}{(50-20)} = \frac{21000}{30} = 700 \text{ units}$$

(with in the range of 601 to 900)

- (ii) The projected demand is between 600 to 650 units.

The break even point for single machine option (i.e., 400 units) is not feasible because it exceeds the range of volume that can be produced with one machine (i.e., 0 to 300).

Also, the break even point for 3 machines is 700 units which is more than the upper limit of projected demand of 600 to 650 units and hence not feasible. For 2 machines option the break even volume is 500 units and volume range is 301 to 600.

Hence, the demand of 600 can be met with 2 machines and profit is earned because the production volume of 600 is more than the break even volume of 500. If the manager wants to produce 650

units with 3 machines, there will be loss because the break even volume with three machines is 700 units. Hence, the manager would choose two machines and produce 600 units.

2.3 Facility Location and Layout

Questions For Classroom Discussion

Question 1

The present layout is shown in the figure. The manager of the department is intending to interchange the department C and F in the present layout. The handling frequencies between the departments is given. All the departments are of same size and configuration. The material handling cost per unit length travel between departments is same. What will be effect of the interchange of departments C and F in the layout?

A	C	E
B	D	F

Handling Frequency or Trip Matrix

From \ To	A	B	C	D	E	F
A	-----	0	90	160	50	0
B	-----	-----	70	0	100	130
C	-----	-----	-----	20	0	0
D	-----	-----	-----	-----	180	10
E	-----	-----	-----	-----	-----	40
F	-----	-----	-----	-----	-----	-----

Question 2

A defense contractor is evaluating its machine shops current process layout. The figure below shows the current layout and table shows the trip matrix for the facility. Health and Safety regulations require departments E and F to remain at their current positions.

E	B	F
A	C	D

Trip Matrix or Handling

	A	B	C	D	E	F
A	-----	8	3	-----	9	5
B	-----	-----	-----	3	-----	-----
C	-----	-----	-----	-----	8	9
D	-----	-----	-----	-----	-----	3
E	-----	-----	-----	-----	-----	3
F	-----	-----	-----	-----	-----	-----

Question 3

Home Work - Previous Year Question (December 2008, Q2(d), 6 Mark)

Mr. X is considering an interchange of departments B and C in the present layout. The present layout and the handling frequencies between the departments are given. What would be the effect of interchange assuming that the departments are of the same size? Also assume that the material handling cost per unit length travel between departments is same.

A	C	E
B	D	F

Handling frequency or Trip Matrix

	A	B	C	D	E	F
A	----	20	70	0	40	0
B	----	----	50	200	0	10
C	----	----	----	30	120	40
D	----	----	----	----	50	220
E	----	----	----	----	----	30
F	----	----	----	----	----	----

Question 4 Home Work - Previous Year Question (December 10, Q3(a), 6 Mark)

Given below is the existing process layout of a factory manufacturing toys :

C	B	D
E	A	F

The following table gives the trip matrix for the unit. Arrive at an improved layout using the Load Distance matrix assuming that E and F should remain at their current positions :

Trip Matrix or Handling Frequency

	A	B	C	D	E	F
A	----	----	2	2	1	----
B	----	----	1	----	6	5
C	----	----	----	1	4	----
D	----	----	----	----	----	5
E	----	----	----	----	----	1
F	----	----	----	----	----	----

Illustration From Study Material

Illustration 9:

Suppose, an E-Commerce company wants to open Central order fulfilment center in Kolkata South in West Bengal. The possible locations are say L_1 , L_2 , and L_3 . The company form a group of experts. The team identifies say 6 actors such as F_1 , F_2 , F_3 , and F_4 to evaluate L_1 to L_3 .

Answer

This situation can be solved using Factor Rating Method. The steps are:

In the first stage the expert team needs to give weightage to the factors. This can be done in many ways. In the following one simple way is explained.

A possible approach:

Suppose, the experts rate each factor on a scale 1 to 5 (1: least important and 5: Most important)

Factor	Rating					Row	Weight
	E-1	E-2	E-3	E-4	E-5		
F_1	4	3	4	4	3	18	18/68
F_2	5	5	5	5	4	24	24/68
F_3	3	4	4	3	5	19	19/68
F_4	2	1	2	1	1	7	7/68
						68	

There may be other ways (e.g., AHP method). Let us now come back to our problem. Let us assume the factors are following weights.

Factors	Weight
F_1	0.3
F_2	0.2
F_3	0.1
F_4	0.4
Total	1.0

The experts are requested to rate each of the location alternatives with respect to the factors, e.g., 10: Most beneficial and 1: Least beneficial

Factors	Alternatives		
	L_1	L_2	L_3
F_1	10	9	7
F_2	7	3	10
F_3	7	5	10
F_4	6	8	5

So the complete table becomes

Factors	Weight	Alternatives		
		L_1	L_2	L_3
F_1	0.3	10	9	7
F_2	0.2	7	3	10
F_3	0.1	7	5	10
F_4	0.4	6	8	5
	Best Location	7.5	7	7.1

Example of calculation

for L_1 : $0.3 \times 10 + 0.2 \times 7 + 0.4 \times 6 = 3 + 1.4 + 0.7 + 2.4 = 7.5$

As per the weighted score Location L_1 is the best location

Illustration 10:

Suppose, XYZ Ltd wants to open a retail shop in Kolkata, West Bengal.

It first selects the 4 locations such as L_1 , L_2 , L_3 and L_4 . The coordinates of the locations (i.e., latitudes and longitudes) and volume of customers (i.e., average number of customers in a day in '000) are given in the following table

Location	Volume	Coordinates	
		X	Y
L_1	200	30	100
L_2	100	90	120
L_3	100	130	130
L_4	200	60	40

Find out the best location using Center of Gravity (COG) method.

Answer

Loc	V_i	x_i	y_i	$v_i x_i$	$v_i y_i$
L_1	200	30	100	6000	20000
L_2	100	90	120	9000	12000
L_3	100	130	130	13000	13000
L_4	200	60	40	12000	8000
	600		Total	40,000	53,000

Therefore, $SV_i = 600$; $Sv_i x_i = 40000$

$Sv_i y_i = 53000$

COG location is given by (X, Y)

$$X = \frac{\sum V_i X_i}{\sum V_i} = 40000/600 = 200/3$$

$$Y = \frac{\sum V_i Y_i}{\sum V_i} = 53000/600 = 265/3$$

Illustration 11:

The present layout is shown in the figure. The manager of the department is intending to interchange the departments C and F in the present layout. The handling frequencies between the departments is given. All the departments are of the same size and configuration. The material handling cost per unit length travel between departments is same. What will be the effect of interchange of departments C and F in the layout?

A	C	E
B	D	F

From / To	A	B	C	D	E	F
A	-	0	90	160	50	0
B	-	-	70	0	100	130
C	-	-	-	20	0	0
D	-	-	-	-	180	10
E	-	-	-	-	-	40
F	-	-	-	-	-	-

Answer

The distance matrix of the present layout :

From / To	A	B	C	D	E	F
A		1	1	2	2	3
B			2	1	3	2
C				1	1	2
D					2	1
E						1
F						-

(ii) Computation of total cost matrix (combining the inter departmental material handling frequencies and distance matrix.

From / To	A	B	C	D	E	F	Total
A		0	90	320	100	0	510
B			140	0	300	260	700
C				20	0	0	20
D					360	10	370
E						40	40
F							-
Total							1,640

If the departments are interchanged, the layout will be represented as shown below.

A	F	E
B	D	C

The distance matrix and the cost matrix are represented as shown.

From / To	A	B	C	D	E	F
A		1	3	2	2	1
B			2	1	3	2
C				1	1	2
D					2	1
E						1
F						

Total cost matrix for the modified layout.

From / To	A	B	C	D	E	F	Total
A	-	0	270	320	100	0	690
B			140	0	300	260	700
C				20	0	0	20
D					360	10	370
E						40	40
F							-

Total							1,820

The interchange of departments C and F increases the total material handling cost. Thus, it is not a desirable modification.

Illustration 12:

A defence contractor is evaluating its machine shops current process layout. The figure below shows the current layout and the table shows the trip matrix for the facility. Health and safety regulations require departments E and F to remain at their current positions.

E	B	F
A	C	D

Current Layout

From / To	A	B	C	D	E	F
A		8	3		9	5
B		-		3		
C			-		8	9
D		-				3
E					-	3
F						-

Can layout be improved? Also evaluate using load distance (ld) score.

Answer

Keep the departments E and F at the current locations. From the Trip Matrix, C is having maximum no. of trips from E&F. So C must be as close as possible to both E and F, put C between them. Place A directly south of E, and B next to A. All of the heavy traffic concerns have been accommodated. Department D is located in the remaining place. The proposed layout is shown in figure below. The load distance (ld) scores for the existing and proposed layout are shown below. As Id score for proposed layout is less, the proposed layout indicates improvement over existing.

E	C	F
A	B	D

Comparative Analysis: Current and Proposed Layout:

Dept. Pair	No. of Trips (1)	Existing plan		Proposed plan	
		Distance (2)	Load × Distance (1 × 2)	Distance (3)	Load × Distance (1 × 3)
A-B	8	2	16	1	8
A-C	3	1	3	2	6
A-E	9	1	9	1	9
A-F	5	3	15	3	15
B-D	3	2	6	1	3
C-E	8	2	16	1	8
C-F	9	2	18	1	9
D-F	3	1	3	1	3
E-F	3	2	6	2	6
Total			92		67

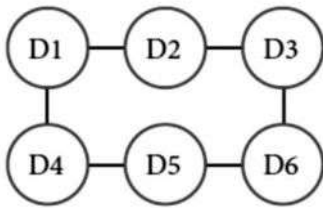
As 'ld' score of the proposed layout is lower than the existing one, there is an improvement in the new layout.



Illustration 13:

Suppose a hospital has 6 major departments namely D1, D2, D3, D4, D5 and D6. The initial layout of the hospital is given below.

Initial Layout



The average traffic movement to and from each department is given in the following table

Table - Average traffic flow (Direct)

	D1	D2	D3	D4	D5	D6
D1	-	10	20	0	5	6
D2	8	-	6	10	0	2
D3	10	6	-	20	7	8
D4	0	25	5	-	10	3
D5	15	10	1	20	-	6
D6	0	6	0	3	4	-

The hospital wants to find out an optimum layout.

Answer

We notice quite obviously that from D_i to D_i ($i = 1, 2, \dots, 6$), there is no movement.

From D2 to D1, the average movement is 10 (circle) and from D1 to D2 the average movement is 8 (circle)

Therefore, the combined average traffic movement from D1 to D2 is $= (10 + 8) = 18$

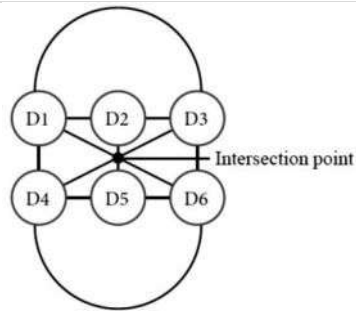
Let us now take another pair, e.g., D4 and D2

Movement	Avg traffic
D4 $\rightarrow$ D2	10 (red circle)
D2 $\rightarrow$ D4	25 (Green circle)

Therefore, the combined average traffic movement is 35. Proceeding in the same way, we get the combined average traffic movement for all pairs as follows:

	D1	D2	D3	D4	D5	D6
D1	-	18	30	0	20	6
D2		-	12	35	10	8
D3			-	25	8	8
D4				-	30	7
D5					-	10
D6						-

Let us now draw the initial layout again.



Adjacent Pairs	Non-adjacent Pairs
D1 & D2 D2 & D3 D3 & D6 D6 & D5 D5 & D4 D2 & D5 D1 & D4 D1 & D5 D3 & D5 D2 & D4 D2 & D6	D1 & D3 D1 & D6 D3 & D4 D4 & D6

Let us now concentrate on the non-adjacent pairs

Non-adjacent Pair	Distance
D1 & D3	$(D1 \rightarrow D2; D2 \rightarrow D3)$ $D1 \rightarrow D3 : 2 \text{ nodal points}$ Hence, distance is 2
D1 & D6	$D1 \rightarrow D6$ $= D1 \rightarrow P \ \& \ P \rightarrow D6$ Distance = 2
D3 & D4	$D3 \rightarrow D4$ $= D3 \rightarrow P \ \& \ P \rightarrow D4$ Distance = 2
D4 & D6	$D4 \rightarrow D6$ $= D4 \rightarrow D5 \ \& \ D5 \rightarrow D6$ Distance = 2

The combined average traffic movement between any two non-adjacent nodes is called the load distance. Our objective is to reduce the load distance.

Non-adjacent Pair	Distance
D1 & D3	$30 \times 2 = 60$
D3 & D4	$25 \times 2 = 50$
D1 & D6	$6 \times 2 = 12$
D4 & D6	$7 \times 2 = 14$
	Total = 136

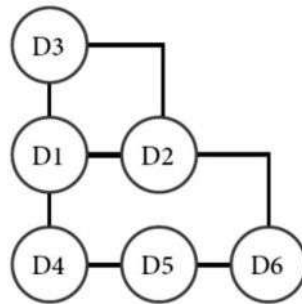
Note that for getting the load values, please refer table (Solution).

To meet our objective, we find the highest load distance, i.e., 60. Therefore, we need to rearrange the nodes.



We notice that from D1 to D3 and back, the highest traffic is involved. Therefore, we need to rearrange their positions to make them adjacent as follows:

First rearrangement

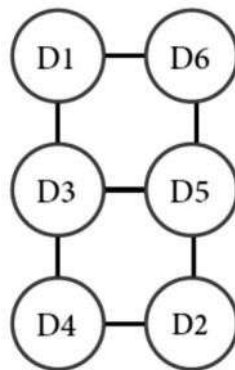


The revised non-adjacent pairs and load distance calculation is given below

Non-adjacent Pair	distance	Load distance
D4 & D6	2	14
D1 & D6	2	12
D3 & D6	2	16
D3 & D5	2	16
D3 & D4	2	50
		108

We notice that there is an improvement. However, now the pair of D3 and D4 creates the problem. Therefore, we need to make them adjacent through rearrangement as follows:

2nd Arrangement



The revised non-adjacent pairs and load distance (after second arrangement) is given below

Non-adjacent Pair	Load	distance	load-distance
D ₁ D ₄	2	0	0
D ₆ D ₂	2	8	16
D ₁ D ₂	2	18	36
D ₆ D ₄	2	7	14
			66

Through trial and error approach we arrive at a considerable improvement. Therefore, the above layout (2nd Arrangement) is the acceptable one.

2.4 Resource Aggregate Planning

Questions For Classroom Discussion

Question 1

ABC company has developed a forecast for the group of items that has the following demand pattern.

Quarter	Demand	Cumulative Demand
1	270	270
2	220	490
3	470	960
4	670	1630
5	450	2080
6	270	2350
7	200	2550
8	370	2920

The firm estimates, it costs Rs 150 per unit to increase production rate, Rs 200 per unit to decrease the production rate. Rs 50 per unit to carry the items in the inventory and Rs 100 per unit, if sub contracted. Compare the costs of the pure strategies?

- 1) Increase or decrease production
- 2) Constant Level of production or Inventory carrying strategy
- 3) Sub Contracting

Illustration From Study Material

Illustration 14:

ABC. Co. has developed a forecast for the group of items that has the following demand pattern

Quarter	Demand	Cumulative demand
1	270	270
2	220	490
3	470	960
4	670	1630
5	450	2080
6	270	2350
7	200	2550
8	370	2920

The firm estimates that it costs Rs. 150 per unit to increase production rate Rs. 200 per unit to decrease the production rate, Rs. 50 per unit per quarter to carry the items in inventory and Rs.100 per unit if subcontracted. Compare the costs of the pure strategies.

Answer**Different pure strategies are**

Plan I In this pure strategy, the actual demand is met by varying the work force size. This means that during the period of low demand, the company must fire the workers and during the period of high demand the company must hire workers. These two steps involve associated costs. In this strategy, the production units will be equal to the demand and values in each period. The cost of the plan is computed in the table below,

Quarter	Demand	Cost of increasing Production level (Rs.)	Cost of decreasing Production level (Rs.)	Total cost of plan (Rs.)
1	270	—	—	—
2	220	—	$50 \times 200 = 10,000$	10,000
3	470	$250 \times 150 = 37,500$	—	37,500
4	670	$200 \times 150 = 30,000$	—	30,000
5	450	—	$220 \times 200 = 44,000$	44,000
6	270	—	$180 \times 200 = 36,000$	36,000
7	200	—	$70 \times 200 = 14,000$	14,000
8	370	$170 \times 150 = 25,500$	—	25,500
	Total			1,97,000

Plan II In this plan, the company computes the average demand and sets its production capacity to this average demand. This results in excess of units in some periods and also shortage of units during some other periods. The excess units will be carried as inventory for future use and shortage of units can be fulfilled using future inventory. The cost of the plan II is computed in the table below. The plan incurs a maximum shortage of 255 units during quarter 5. The firm might decide to carry 255 units from the beginning of period 1 to avoid shortage. The total cost of the plan is Rs. 96,500.

Quarter	Demand forecast	Cumulative demand	Production level = Av. Demand = $2920 \div 8$	Cumu. prod. level	Inventory = (Cum. Production - Cum. Demand)	Adjusted inventory with 255 at beginning of period 1	Cost of holding inventory (Rs.)



1	270	270	365	365	95	350	17,500
2	220	490	365	730	240	495	24,750
3	470	960	365	1095	135	390	19,500
4	670	1630	365	1460	-170	85	4,250
5	450	2080	365	1825	-255	0	0
6	270	2350	365	2190	-160	95	4,750
7	200	2550	365	2555	5	260	13,000
8	370	2920	365	2920	0	255	12,750
	Total						96,500

Plan III

Normal Production Capacity is assumed to be 200 units i.e. Minimum of the demand values. The additional demand other than the normal capacity is met by subcontracting. The cost of the plan III amounts to Rs. 1,32,000 as shown in table below.

Quarter	Demand forecast	Production units	Subcontract units	Incremental cost @ Rs. 100/units
1	270	200	70	$70 \times 100 = 7,000$
2	220	200	20	$20 \times 100 = 2,000$
3	470	200	270	$270 \times 100 = 27,000$
4	670	200	470	$470 \times 100 = 47,000$
5	450	200	250	$250 \times 100 = 25,000$
6	270	200	70	$70 \times 100 = 7,000$
7	200	200	0	0
8	370	200	170	$170 \times 100 = 17,000$
			Total	= 1,32,000

The total cost of pure strategies is given below. On observation Plan II (Changing inventory levels) has the least cost.

Plan	Total cost (Rs.)
Plan I	1,97,000
Plan II	96,500
Plan III	1,32,000

Illustration 15:

A firm has developed the following forecast (units) for an item which has a demand influence by seasonal factors.

Month	Forecasted Demand	Production Days
Jan	220	22
Feb	90	18
Mar	210	21
Apr	396	22
May	616	22
Jun	700	20
Jul	378	21
Aug	220	22
Sep	200	20



Oct	115	23
Nov	95	19
Dec	260	20

- (a) Prepare a chart showing the daily demand requirements.
- (b) Determine the production rate required to meet average demand.
- (c) Determine the monthly inventory balance required to follow a plan with:
1. Constant workforce
 2. No idle time or overtime
 3. No Backorder
 4. No use of Sub-Contractor
 5. No capacity adjustment
- (d) The firm has determined that to follow a plan of meeting demand by varying the size of the workforce strategy
Put result in hiring and lay-off cost estimated at Rs.12000. If the unit cost is Rs.100 each to produce, carrying cost per year are 20% of the average inventory value and storage cost (based upon maximum inventory) are Rs.0.90 per unit which plan results in the lower cost, varying inventory or varying employment? [Where Plan 1 indicates varying inventory and Plan 2 indicates varying Employment]
- (e) Suppose the firm wishes to investigate two other plans (alternatives). A third plan is to produce at a rate of 10 units per day and sub-contract the additional requirements at a delivered cost of Rs.107 per unit.
Any accumulated inventory is carried forward at a 20% carrying cost (No extra Storage cost).
The Fourth Plan is to produce at a steady rate of 10 units per day and use overtime to meet the additional requirement at a premium of Rs.10 per unit. Accumulated inventory is again carried forward at a 20% cost.
- (f) Compare 4 plans given in Question (d) and (e) and comment which plan gives the minimum cost.

Answer

Chart of Production Requirement

Month	Forecasted Demand	Production Days	Demand/Day	Cumulative Production Days	Cumulative Demand
Jan	220	22	10	22	220
Feb	90	18	5	40	310
Mar	210	21	10	61	520
Apr	396	22	18	83	916
May	616	22	28	105	1532
Jun	700	20	35	125	2232
Jul	378	21	18	146	2610
Aug	220	22	10	168	2830
Sep	200	20	10	188	3030
Oct	115	23	5	211	3145
Nov	95	19	5	230	3240
Dec	260	20	13	250	3500
Total	3500				

- (a) Average Requirement = Total Demand / Total Production Days = 3500/25 = 14units/day
- (b) Inventory Balance = $\sum$ Production - $\sum$ Demand



Showing the ending Inventory Balance and Ending Balance with Negative Shortage.

Month	Production at 14/day	Forecasted Demand	Inventory Change	Ending Inventory	Balance Ending Balance adjusted in the month of Jan
Jan	308	220	88	88	654
Feb	252	90	162	250	816
Mar	294	210	84	334	900
Apr	308	396	-88	246	812
May	308	616	-308	-62	504
Jun	280	700	-420	-482	84
Jul	294	378	-84	-566	0
Aug	308	220	88	-478	88
Sep	280	200	80	-398	168
Oct	322	115	207	-191	375
Nov	266	95	171	-20	546
Dec	280	260	20	0	566

(c) Maximum Inventory required in storage = 900 units (in the above table Column 6)

Average Inventory Balance = 460 units

Solution to Plan 1 (Varying Inventory):

Inventory Cost = Carrying Cost + Storage Cost

Carrying Cost = $0.20 \times 460 \times 100 = 9200$

Storage Cost = $900 \times 0.90 = 810$

Inventory Cost = Rs.10010

Solution to Plan 2 (Varying Employment):

Rs.12000 (Given)

Comparing Plan 1 and Plan 2 we see that Plan 1 is lower.

In case of Plan 3:

it is given that Produce at 10 units per day, vary inventory and sub-contract.

A production rate of 10 units per day exceeds demand only 3 months (Feb, Oct, Nov)

Month	Production at 10/day	Forecasted Demand	Inventory Change
Jan	220	220	0
Feb	180	90	90
Mar	210	210	0
Apr	220	396	-176
May	220	616	-396
Jun	200	700	-500
Jul	210	378	-168
Aug	220	220	0
Sep	200	200	0
Oct	230	115	115
Nov	190	95	95
Dec	200	260	-60



The Inventory Accumulated During these Years must be carried at a cost of (20%) (Rs.100) /12 Months = Rs.1.67 per unit month. Units are Carried until they can be used to help meet demand in a subsequent month

Assume, an equilibrium condition where the excess production from OCT and NOV (150 Units) is on hand JAN

Month	Demand	Production at 10/day	Inventory to carry	Inventory carried until	No. of Months	Cost at \$1.67 per unit month
Initial			150	150 units to April	3	750
Feb	90	180	90	26 units to April	2	87
				64 units to May	3	320
Oct	115	230	115	60 units to Dec	2	200
				55 units to Year End	3	275
Nov	95	190	95	95 units to Year End	2	317
					Total	1952

Therefore, Inventory Cost from above = Rs.1952

Calculating Marginal Cost of Sub-contracting:

The marginal cost of sub-contracting

Number of units = Demand - Production = 3500 - (10 × 250) = 1000 units for sub-contracting

Therefore, Cost per unit = Rs.107 - Rs.100 = Rs.7 per unit

Therefore, Marginal Cost = 1000 units × Rs.7 per unit = Rs.7000

The total Cost of Plan 3 = Inventory Cost + Sub-contracting cost = 1952 + 7000 = Rs.8952

Plan 4:

This plan differs from plan 3 only in the marginal cost which is now due to overtime rather than sub-contracting.

So, Inventory cost (same as plan 3) i.e., Rs.1952 and Marginal cost of Overtime = 1000 units × rate of Rs.10 per unit = Rs.10,000

Therefore, total cost of Plan 4 = Rs.10,000 + Rs.1952 = Rs.11952

Table: Comparison of Plans

Plan	Strategy	Cost
Plan 1	Pure Strategy (Vary Inventory)	Rs.10010
Plan 2	Pure Strategy (Vary Employment)	Rs.12000
Plan 3	Mixed Strategy (Sub-contract and Vary Inventory)	Rs.8952
Plan 4	Mixed Strategy (Overtime and Vary Inventory)	Rs.11952

2.7 Economic Batch Quantity

Questions For Classroom Discussion

Question 1

XYZ company carries a wide assortment of items for its customers. One Item 'A' is very popular. Desires of keeping its inventory under control, a decision is taken to order only the optimal economic quantity, for this item, each time. Given Annual Demand, 160,000 units. Price per unit: Rs 20, Carrying cost Rs 4 per unit. Cost of order Rs 50.

Develop the following and from the table determine the optimal order quantity.

Number of Order	1	10	20	40	80	100
Order Quantity						
Average Inventory						
Order Cost @ 50						
Carrying Cost @ 4						
Total inventory Management Cost						

Question 2

The monthly requirement of raw material for a company is 3000 units. The carrying cost is estimated to be 20% of the purchase price per unit, in addition to Rs 2 per unit. The purchase price of raw material is Rs 20 per unit. The ordering cost is Rs 25 per order.

Q.1 You are required to find EOQ.

Q.2 What is the total cost when the company gets a concession of 5% on the purchase price if it orders 3000 units or more but less than 6000 units per month

Q.3 What happens when the company gets a concession of 10% on the purchase price when it orders 6,000 units or more?

Q.4 Which of the above three ways of orders the company should adopt?

Question 3

M/s Kobo Bearings Ltd., is committed to supply 24,000 bearings per annum to M/s Deluxe Fans on a steady daily basis. It is estimated that it costs 10 paise as inventory holding cost per bearing per month and that the setup cost per run of bearing manufacture is Rs 324.

Q.1 What is the optimum run size for bearing manufacture?

Q.2 What should be the interval between the consecutive optimum runs?

Q.3 Find out the minimum inventory management cost.

Question 4

Shravan Tubes Ltd. are the manufacturers of picture tubes of T.V. The following are the details of their operation during 2001:

- Average monthly market demand 2,000 tubes
- Ordering cost Rs 100 per order.
- Inventory carrying cost 20% per annum.
- Cost of tubes Rs 500 per tube.
- Normal usage 100 tubes per week.
- Minimum usage 50 tubes per week.
- Maximum usage 200 tubes per week.

- Lead time to supply 6 - 8 weeks

Find

- Q.1 Economic order quantity. If the supplier is willing to supply quarterly 1,500 units at a discount of 5%, is it worth accepting?
- Q.2 Maximum level of stock.
- Q.3 Minimum level of stock.
- Q.4 Re-order level of stock.

Illustration From Study Material

Illustration 16:

The monthly requirement of raw material for a company is 3000 units. The carrying cost is estimated to be 20% of the purchase price per unit, in addition to Rs. 2 per unit. The purchase price of raw material is Rs. 20 per unit. The ordering cost is Rs. 25 per order. (i) You are required to find EOQ. (ii) What is the total cost when the company gets a concession of 5% on the purchase price if it orders 3000 units or more but less than 6000 units per month. (iii) What happens when the company gets a concession of 10% on the purchase price when it orders 6,000 units or more? (iv) Which of the above three ways of orders the company should adopt?

Answer:

We are given that,

A = Annual demand = $3,000 \times 12 = 36,000$ units per annum ; S = Ordering Cost = Rs. 25;

C = Inventory carrying cost = $2 + 20\%$ of Rs. 20 = $2 + 4 =$ Rs. 6

$$(i) \text{ EOQ} = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{6}} = \sqrt{30,00,000} = 548 \text{ units (approx.)}$$

$$\begin{aligned} \text{Total cost} &= \text{Ordering Cost} + \text{Cost of purchasing the material} + \text{Storage cost} \\ &= (36,000 / 548) \times 25 + (36,000 \times 20) + (548/2) \times 6 \quad [\because \text{Storage cost} = \text{Average Inventory} \times \text{Inventory carrying cost}] \\ &= \text{Rs. } 1642.33 + 7,20,000 + 1,644 = \text{Rs. } 7,23,286. = \frac{\text{EOQ}}{2} \times 6] \end{aligned}$$

(ii) When the company has an option to order between 3000 and 6000 units, the EOQ should be calculated with a reduction in price by 5% (due to concession); The purchase price = 95% of Rs. 20 = Rs. 19.

A = 36,000 units per annum; S = Rs. 25; C = $2 + 20\%$ of 19 = $2 + 3.80 =$ Rs. 5.80

$$\text{EOQ} = \sqrt{\frac{2 \times 36000 \times 25}{5.80}} = \sqrt{\frac{1,80,000}{5.80}} = 557 \text{ units (approx.)}$$

$$\begin{aligned} \text{Total cost} &= (36,000/557) \times 25 + (36,000 \times 19) + (557/2) \times 5.80 \\ &= \text{Rs. } (1,615.79 + 6,84,000 + 1,615.30) = \text{Rs. } 6,87,231.09 \end{aligned}$$

For monthly order quantity being 3000 units or more but less than 6000 units

EOQ = 557 units

$$\text{No. of orders per year} = \frac{\text{Yearly demand}}{\text{EOQ}} = \frac{36000}{557} = N(\text{Let})$$

$$\text{No. of orders per month} = \frac{N}{12} = \frac{36000/557}{12} = 5.385 = 6(\text{Say}) = N^*$$

$$\text{Quantity to be ordered per month} = N^* \times \text{EOQ} = 6 \times 557 = 3342 \text{ units}$$

This quantity lies in the range of 3000 to 6000 units

Hence the EOQ (557 units) can be considered to be a feasible quantity for availing 5% discount on Purchase Price.

(iii) When the company orders more than 6,000 units purchase price = 90% of Rs. 20 (because 10% concession)

= Rs. 18; A = 36,000 units per annum; S = Rs. 25; C = $2 + 20\%$ of Rs. 18

= $2 + 3.60 = 5.60$

$$\text{EOQ} = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{5.60}} = 567 \text{ units app.}$$

For monthly order quantity more than or equal to 6000 units

EOQ = 567 units

$$\text{No of orders per month} = \frac{36000/567}{12} = 5.29 = 6(\text{Say}) = N^*$$

$$\text{Qty. to be ordered per month} = N^* \times \text{EOQ} = 6 \times 567 = 3402 \text{ units}$$

This quantity does not lie in the range of 6000 or more units.

Hence the EOQ (567 units) can not be considered as feasible quantity for availing 10% discount on Purchase Price.

To understand the effect of 10% on Total Cost, we consider the minimum value of price break quantity of this range i.e. 6000 units to be the optimum order quantity and calculate.

Total Cost as follows —

TC = Ordering Cost + Cost of Purchasing the material + Storage Cost

$$= \frac{36000}{6000} \times 25 + 36000 \times 18 + \frac{6000}{2} \times 5.60$$

$$= 150 + 648000 + 16800 = \text{Rs. } 6,64,950$$

Hence the total cost will be minimum (Rs. 6,64,950) if orders are placed in lot size of 6000 units.

Illustration 17:

M/s. Tubes Ltd. are the manufacturers of picture tubes of T.V. The following are the details of their operation during 2001:

Average monthly market demand	2,000 tubes
Ordering cost	Rs. 100 per order
Inventory carrying cost	20% per annum
Cost of tubes	Rs. 500 per tube
Normal usage	100 tubes per week
Minimum usage	50 tubes per week
Maximum usage	200 tubes per week
Lead time to supply	6 - 8 weeks

Compute from the above:

- (1) Economic order quantity. If the supplier is willing to supply quarterly 1,500 units at a discount of 5%, is it worth accepting?
- (2) Maximum level of stock.
- (3) Minimum level of stock.
- (4) Re-order level of stock.

Answer

(1) Economic Order Quantity:

$$\begin{aligned} \text{Annual usage of tubes (A)} &= \text{Normal usage per week} \times 52 \text{ weeks} \\ &= 100 \text{ tubes} \times 52 \text{ weeks} \\ &= 5,200 \text{ tubes.} \end{aligned}$$

$$\text{Ordering cost per order (S)} = \text{Rs. } 100.$$

$$\text{Inventory carrying cost per unit per annum (C)} = 20\% \text{ of Rs. } 500 = \text{Rs. } 100.$$

$$\text{EOQ} = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 5200 \text{ units} \times 100}{100}} = 102 \text{ units (approx.)}$$

(A) Evaluation of order size of 1,500 units at 5% discount

$$\text{No. of orders} = \frac{5,200 \text{ units}}{1,500 \text{ units}} = 3.46 \text{ or } 4 \text{ (in case of a fraction, the next whole number is considered).}$$



	Rs.
Ordering cost (No. of order per year at Rs. 100 per order)	400
Carrying cost of average inventory:	
$\frac{1,500 \text{ units}}{2} \times \text{Rs.}(50 \text{ less } 5\%) \times \frac{20}{100}$	71,250
Total annual cost (excluding item cost)	71,650
(B) Annual cost if EOQ (102 units) is adopted :	Rs.
Ordering cost: $5,200 \div 102$ or 51 orders per year at Rs.100 per order	5,100
Carrying cost of average inventory $\frac{102 \text{ units}}{2} \times \text{Rs.}500 \times \frac{20}{100}$	5,100
Total annual cost (excluding item cost)	10,200

Increase in annual cost by adopting (A) above : Rs. (71,650 - 10,200) = Rs. 61,450.

Amount of quantity discount: $5\% \times \text{Rs. } 500 \times 5,200 \text{ units} = \text{Rs. } 1,30,000$.

Since the amount of quantity discount (Rs. 1,30,000) is more than the increase in total annual cost (Rs. 61,450), it is advisable to accept the offer. This will result in a saving of Rs. (1,30,000 - 61,450) or Rs. 68,550 p.a. in inventory cost.

(2) Maximum Level of Stock:

= Re-order level + Re-order quantity - (Minimum usage $\times$ Minimum delivery period) = 1,600 units + 102 units - (50 units $\times$ 6 weeks) = 1,402 units.

[Assume that the Reorder quantity is supplied as soon as the Reorder level is reached]

(3) Minimum Level of Stock:

= Re-order level - (Normal usage $\times$ Normal delivery period) [see Note] = 1,600 units - (100 units $\times$ 7 weeks)

= 900 units. Note: Normal delivery period is taken to be the average delivery period.

(4) Re-order Level of Stock:

= Maximum usage $\times$ Maximum delivery period = 200 units $\times$ 8 weeks = 1,600 units.

Illustration 18:

M/s Kobo Bearings Ltd., is committed to supply 24,000 bearings per annum to M/s Deluxe Fans on a steady daily basis. It is estimated that it costs 10 paisa as inventory holding cost per bearing per month and that the setup cost per run of bearing manufacture is Rs. 324.

(a) What is the optimum run size for bearing manufacture?

(b) What should be the interval between the consecutive optimum runs?

(c) Find out the minimum inventory holding cost.

Answer

(a) Optimum run size or Economic Batch Quantity (EBQ)

$$\sqrt{\frac{2 \times \text{Annual Output} \times \text{Setup cost}}{\text{Annual Cost of Carrying one unit}}} = \sqrt{\frac{2 \times 24000 \times 324}{0.10 \times 12}} = 3600 \text{ units}$$

(b) Interval between two consecutive optimum runs = $\frac{\text{FBQ}}{\text{Monthly Output}} \times 30$

$$= \frac{3600}{24000 \div 12} \times 30 = 54 \text{ Calendar days}$$

(c) Minimum inventory holding cost = Average inventory $\times$ Annual carry-ing cost of one unit of inventory
= $(3600 \div 2) \times 0.10 \times 12 = \text{Rs. } 2,160$.



Illustration 19:

A company planning to manufacture a household cooking range has to decide on the location of the plant. Three locations are being considered viz., Patna, Ranchi, and Dhanbad. The fixed costs of the three location are estimated to be Rs.30 lakh, Rs.50 lakh, and Rs.25 lakh per annum respectively. The variable costs are Rs.300, Rs.200 and Rs.350 per unit respectively.

The expected sales price of the cooking range is Rs.700 per unit Find out:

- The range of annual production/sales volume for which each location is most suitable and
- Which one of the three locations is the best location at a production/sales volume of 18,000 units?

Answer

The total cost of the three locations are:

At Total cost = Fixed cost + Variable cost for a volume "X"

Patna => Total cost = 30,00,000 + 300 × X

Ranchi => Total cost = 50,00,000 + 200 × X

Dhanbad => Total cost = 25,00,000 + 350 × X

We can compute and plot the total costs per annum at the three different locations for the various cases of production volume of 5,000, 10,000, 15,000, 20,000 25,000 units.

(i) Patna

Volume (x Units)	5,000	10,000	15,000	20,000	25,000
Fixed Cost (Rs.)	30,00,000	30,00,000	30,00,000	30,00,000	30,00,000
Variable Cost (Rs. 300 x)	300 (5,000)	300 (10,000)	300 (15,000)	300 (20,000)	300 (25,000)
Total Cost (Rs.)*	= Rs.45 lakhs	= Rs.60 lakhs	= Rs.75 lakhs	= Rs.90 lakhs	= Rs.105 lakhs

(ii) Ranchi

Volume (x Units)	5,000	10,000	15,000	20,000	25,000
Fixed Cost (Rs.)	50,00,000	50,00,000	50,00,000	50,00,000	50,00,000
Variable Cost (Rs. 200 x)	200 (5,000)	200 (10,000)	200 (15,000)	200 (20,000)	200 (25,000)
Total Cost (Rs.) *	= Rs.60 lakhs	= Rs.70 lakhs	= Rs.80 lakhs	= Rs.90 lakhs	= Rs.100 lakhs

(iii) Dhanbad

Volume (x Units)	5,000	10,000	15,000	20,000	25,000
Fixed Cost (Rs.)	25,00,000	25,00,000	25,00,000	25,00,000	25,00,000
Variable Cost (Rs. 300x)	350 (5,000)	350 (10,000)	350 (15,000)	350 (20,000)	350 (25,000)
Total Cost (Rs.)*	= Rs.42.5 lakhs	= Rs.60 lakhs	= Rs.77.5 lakhs	= Rs.95 lakhs	= Rs.112.5 lakhs

* In all the above tables, Total Cost = Fixed Cost + Variable Cost

If the volume distribution be as follows:

	Up to 10,000 units	Between 10,000 units to 20,000 units	Above 20,000 units
Favourable Location	Dhanbad	Patna	Ranchi

For a volume of 18000 units favourable location is Patna which can be substantiated by the followings calculations of Total Cost :-

Patna => 30,00,000 + 300 × 18,000 = Rs.84 lakhs

Ranchi $\Rightarrow 50,00,000 + 200 \times 18,000 = \text{Rs.}86 \text{ lakhs}$

Dhanbad $\Rightarrow 25,00,000 + 350 \times 18,000 = \text{Rs.}88 \text{ lakhs.}$

Illustration 20:

Monthly demand for a component is 1000 units. Setting-up cost per batch is Rs. 120. Cost of manufacture per unit is Rs. 20. Rate of interest may be considered at 10% p.a. Calculate the EBQ.

Answer:

Calculation of EBQ:

$$\text{EBQ} = \sqrt{\frac{2 \times \text{Annual Demand} \times \text{Setup cost}}{\text{Unit Cost} \times \text{Inventory Carrying cost per unit per year}}} = \sqrt{\frac{2 \times 12 \times 1000 \times 120}{(0.10 \times 20)}} = 1200 \text{ units}$$

Illustration 21:

Based on the following data on the exports of an item by a company during the various years fit a straight line, (for the time being, assume that a straight line gives a good fit). Give a forecast for the years 2013 and 2014.

Year	No. of items ('000)
2004	13
2005	20
2006	20
2007	28
2008	30
2009	32
2010	33
2011	38
2012	43

Answer:

We can call the years as 'X' and exports as 'Y'. In order to use the normal equations for the least square line, we need ΣX , ΣY , ΣXY and ΣX^2 . If we arrange X in such a way that $\Sigma X = 0$, it will simplify our calculations. Therefore, we call the year 2008 as 0, 2007 as -1 and 2009 as +1 and likewise for the other years in the data.

The rearrangement is shown in the table as follows:

X	Y	X ²	XY
-4	13	16	-52
-3	20	9	-60
-2	20	4	-40
-1	28	1	-28
0	30	0	0
1	32	1	32
2	33	4	66
3	38	9	114
4	43	16	172
$\Sigma X = 0$	$\Sigma Y = 257$	$\Sigma X^2 = 60$	$\Sigma XY = 204$

Let the equation of the best fit straight line to the given data be $Y = a_0 + a_1X$

So the normal equations are

$$\Sigma Y = a_0 N + a_1 \Sigma X \quad \dots\dots\dots (1)$$

$$\Sigma XY = a_0 \Sigma X + a_1 \Sigma X^2 \quad \dots\dots\dots (2)$$

As $\Sigma X = 0$, from (1) $\Sigma Y = a_0 N$ from (2) $\Sigma XY = a_1 \Sigma X^2$

Therefore, $a_0 = \Sigma Y / N = 257 / 9 = 28.56$ [N = No. of years]

$$a_1 = \Sigma XY / \Sigma X^2 = 204 / 60 = 3.4$$

The equation of a straight line fitting the data is:

$$Y = 28.56 + 3.4 X$$

(a) Forecast for 2013, (i.e., $X = 5$): $Y = 28.56 + 3.4 (5) = 45.56$ ('000) nos.

(b) Forecast for 2014, (i.e., $X = 6$): $Y = 28.56 + 3.4 (6) = 48.96$ ('000) nos.

Illustration 22:

Find the economic order quantity and the reorder point, given

Annual demand (D) = 1000 units

Average daily demand (d) = $1000/365$

Ordering Cost (S) = Rs. 5 per order

Holding cost(H) = Rs. 1.25 per unit per year.

Lead time (L) = 5 days

Cost per unit (C) = Rs. 12.50

What quantity should be ordered?

Answer:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 1000 \times 5}{1.25}} = \sqrt{8000} = 89.44 \text{ units}$$

$$\text{Re-order unit} = dL = \frac{1000}{365} \times 5 = 13.7 \text{ units}$$

$$\begin{aligned} \text{Total Cost} &= DC + \frac{D}{Q} \times S + \frac{Q}{2} \times H = 1000 \times 12.5 + (1000 / 89.44) \times 5 + (89.44 / 2) \times 1.25 \\ &= \text{Rs. } 2611.81 \end{aligned}$$

Illustration 23:

Consider an economic order quantity case where annual demand $D=1000$ units, economic order quantity $Q= 200$ units , the desired probability of not stocking out $P=0.95$, the standard deviation of demand during lead time $6L = 25$ units and lead time = $L=15$ days. Determine the reorder point. Assume the demand is over a 250 week day year.

Answer:

$$d = D/\text{no. week days} = 1000/250 = 4$$

$$\text{Re-order level(R)} = dL + z L = 4 \times 15 + 1.64 \times 25 = 101$$

Illustration 24:

Daily demand for a certain product is normally distributed with a mean of 60 and standard deviation of 7. The source of supply is reliable and maintain a constant lead time of six days. The cost of placing the order is Rs.10 and annual holding costs are Rs.0.50 per unit. There are no stock out costs, and unfilled orders are filled as soon as the order arrives. Assume sales occur over the entire 365 days of the year. Find the order quantity and reorder point to satisfy a 95 percent probability of not stocking out during the lead time.

Answer:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times (60 \times 365)}{0.5}} = \sqrt{876000} = 936 \text{ units}$$

$$\sigma_1 = \sqrt{\sum_{i=1}^L \sigma_d^2} = \sqrt{6 \times 7^2} = 17.15$$

$$\text{Re-order level}(R) = dL + z \sigma_L = 60 \times 6 + 1.64 \times 17.15 = 188$$

Illustration 25:**Fixed -Time period Model with safety stock**

Daily demand for a product is 10 units with a standard deviation of 3 units. The review period is 30 days, and lead time is 14 days. Management has set a policy of satisfying 98% of demand from items in stock. At the beginning of this review period, there are 150 units in inventory.

Answer:

$$Q = d(T+L) + z \sigma_{T+L} - I = 10(30+14) + z \sigma_{T+L} - 150 =$$

$$\sigma_{T+L} = \sqrt{\sum_{i=1}^{T+L} \sigma_d^2} = \sqrt{(T+L)\sigma_d^2} = \sqrt{(30+40) \times 3^2} = 19.90$$

T for P = 0.98 is 2.05

$$Q = 160 - 150 + 2.05 \times 19.9 = 331 \text{ units}$$

Illustration 26:**Average Inventory calculation - Fixed order quantity model**

Suppose the following item is being managed using a fixed order quantity model with safety stock

Annual Demand (D) = 1000 units

Order quantity (Q) = 300 units

Safety stock (SS) = 40 units

What are the average inventory level and inventory turn for the item?

Answer:

$$\text{Avg. Inventory} = Q/2 + SS = 150 + 40 = 190$$

$$\text{Inventory Turn} = \frac{D}{\frac{Q}{2} + SS} = \frac{1000}{190} = 5.263 \text{ turn per year}$$

Illustration 27:**Average Inventory calculation - Fixed Time period model**

Consider the following item that is being managed using a fixed time period model with safety stock

Weekly demand (d) = 50 units

Review cycle (T) = 3 weeks

Safety stock (SS) = 30 units

What are the average inventory level and inventory turn for the item?

Answer:

$$\text{Avg. Inventory} = dT/2 + SS = (50 \times 3)/2 + 30 = 105 \text{ units}$$

$$\text{Inventory Turn} = \frac{52d}{\text{Avg. Inventory}} = \frac{52 \times 50}{105} = 24.8 \text{ turn per year}$$

Illustration 28:**Price Break Problem**

Consider the following case, where

D = 10000 units (annual demand)

S = Rs. 20 to place order

I = 20 percent of cost (annual carrying cost, storage, interest, obsolescence, etc)

C = Cost per unit (according to the order size: order of 0 to 499 units, Rs.5.00 per unit; 500 to 999 units, Rs.4.50 per unit; 1000 and up, Rs.3.90 per unit)

What quantity should be ordered?

Answer:

$$EOQ1 = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2 \times 10000 \times 20}{20 \times 5}} = 63.24$$

$$EOQ2 = \sqrt{\frac{2 \times 10000 \times 20}{20 \times 4.5}} = 66.67$$

$$EOQ3 = \sqrt{\frac{2 \times 10000 \times 20}{20 \times 3.9}} = 71.6$$

$$\text{Total Cost1} = DC + \frac{D}{Q} \times S + \frac{Q}{2} \times iC = 56323$$

$$TC2 = 51000$$

$$TC3 = 44585.69$$

1000 units should be ordered.

Illustration 29:

A product is priced to sell at Rs.100 per unit, and its cost is constant at Rs.70 per unit. Each unsold unit has a salvage value of Rs.20. Demand is expected to range between 35 and 40 units for the period. 35 definitely can be sold and no units over 40 will be sold. The demand probabilities and the associated cumulative probability distribution (P) for this situation follows.

Number of Units	Demand Probability of this Demand	Cumulative Probability
35	0.10	0.10
36	0.15	0.25
37	0.25	0.50
38	0.25	0.75
39	0.15	0.90
40	0.10	1.00

How many units should be ordered?

Answer:

The cost of underestimating the demand is loss of profit (Cu) or 100-70=30/unit. The cost of overestimating demand is the loss incurred when the unit must be sold at salvage value(Co)

$$= 70 - 20 = 50$$

The optimal prob. Of not being sold

$$P \leq C_u / C_o + C_u = 30 / 30 + 50 = 0.375$$

From the data, this corresponds to 37th value.

No. of unit sold

Unit demand	Prob.	35	36	37	38	39	40
35	0.1	0	50	100	150	200	250
36	0.15	30	0	50	100	150	200
37	0.25	60	30	0	50	100	150
38	0.25	90	60	30	0	50	100
39	0.15	120	90	60	30	0	50
40	0.1	150	120	90	60	30	0
Total	1	75	53	43	53	83	125

Illustration 30:

A company currently has 200 units of a product on hand that it orders every two weeks when the salesperson visits the premises. Demand for the product averages 20 units per day with a standard deviation of 5 units. Lead time for the product to arrive is seven days. Management has a goal of 95 percent probability of not stocking out for this product. The salesperson is due to come in late this afternoon when 180 units are left in stock (assuming that 20 are sold today). How many units should be ordered?

Answer:

$$S.D = \sqrt{21(5) \times (5)} = 23$$

$$Z = 1.64$$

$$\begin{aligned} q &= d \times (T + L) + Z \times S.D - I \\ &= 20(14 + 7) + 1.64 \times 23 - 180 \\ &= 278 \text{ units} \end{aligned}$$

Illustration 31:

Solve the ABC analysis of the following table and show graphically taking Percentage of total list of different stock items as x axis and Percentage of total inventory value along y axis

Annual Usage if Inventory by Value

Item Number	Annual Rupee Usage (Rs.)	Percentage of total value (%)
22	95000	40.69
68	75000	32.13
27	25000	10.71
03	15000	6.43
82	13000	5.57
54	7500	3.21
36	1500	0.64
19	800	0.34
23	425	0.18
41	225	0.10
TOTAL	Rs. 233450	100%

Answer:

Classification	Item no.	Annual Rupee Usage	% of total
A	22,68	1,70,000	72.9%
B	27,03,82	53,000	22.7%
C	54,36,19,23,41	10,450	4.5%

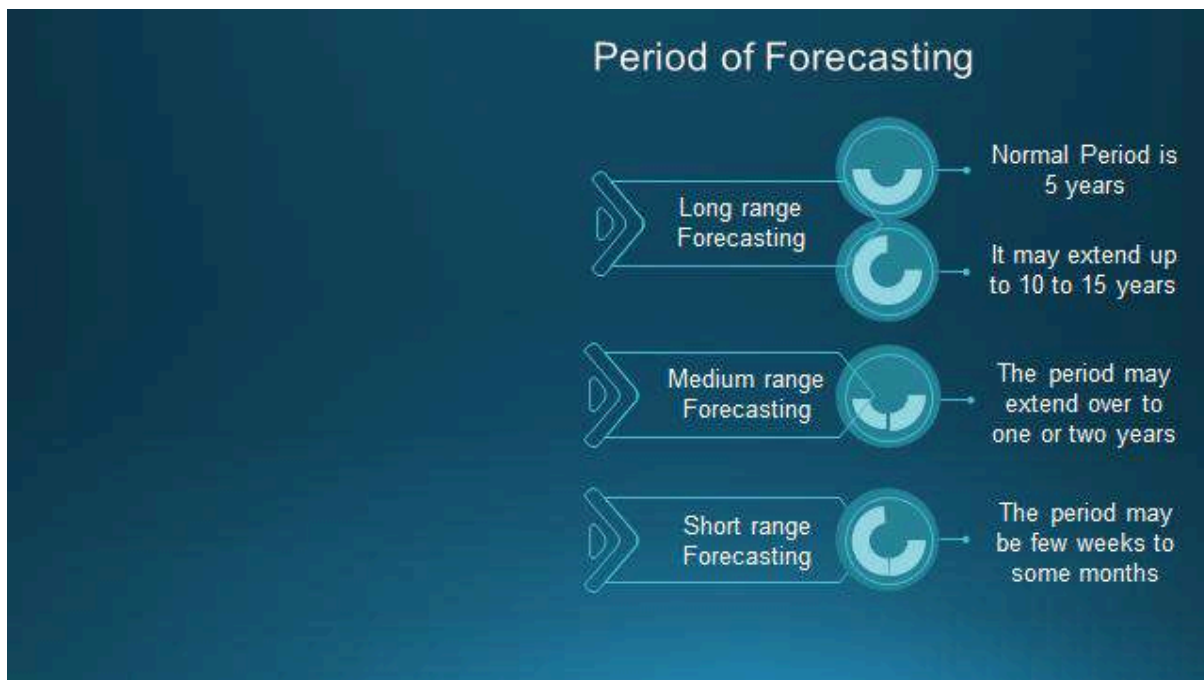
THEORY QUESTIONS

Short Essay

Question 1. Depending up on the time period selected on forecasting, Forecasting can be classified into Long range, Medium Range and Short Range. Please Explain ?

Alternative Questions

1. What are the different time periods used in demand forecasting?
2. How is forecasting classified based on the time period selected?
3. Explain the classification of forecasting into short range, medium range, and long range.
4. What are the purposes of long range, medium range, and short range forecasting?
5. Describe the different purposes for which long range, medium range, and short range forecasts are used.



Essay on Period of Forecasting

Period of Forecasting

Forecasting is a crucial aspect of business planning and decision-making. It involves predicting future events and trends to make informed decisions. The period of forecasting, or the time range selected for forecasting, depends on the **purpose** for which the forecast is made. This period can vary from one week to several years and is generally classified into three categories: short range, medium range, and long range.

Long Range Forecasting

Long range forecasting typically covers a period of several years. It is used for strategic planning and involves making predictions about future developments that will significantly impact the organization. The purposes of long range forecasting include:

- **Capital Expenditure Planning:** Estimating the funds required for future developments or acquiring new facilities.
- **Cash Flow Projections:** Determining the expected cash flow from sales over an extended period.
- **Manpower Planning:** Forecasting future manpower requirements to ensure the organization has the necessary human resources.
- **Material Requirement Planning:** Estimating the materials needed for future production.

- **Research and Development:** Planning for future R&D activities to stay competitive and innovative. For example, a company planning to expand its operations to a new country would use long range forecasting to estimate the capital investment required, the expected sales revenue, and the manpower needed over the next five years.

Medium Range Forecasting

Medium range forecasting usually spans a period of one to three years. It is used for tactical planning and involves making predictions that help in managing the organization's resources more effectively. The purposes of medium range forecasting include:

- **Budgetary Control:** Determining budgetary control over expenses to ensure financial stability.
- **Dividend Policy:** Deciding on the dividend policy based on expected profits.
- **Maintenance Expenses:** Estimating and controlling maintenance expenses.
- **Operations Scheduling:** Planning the schedule of operations to optimize productivity.
- **Capacity Adjustments:** Planning for capacity adjustments to meet changing demand.

For instance, a manufacturing company might use medium range forecasting to plan its production schedule, budget for maintenance costs, and adjust its capacity to meet anticipated demand over the next two years.

Short Range Forecasting

Short range forecasting covers a period of up to one year. It is used for operational planning and involves making predictions that help in day-to-day management of the organization. The purposes of short range forecasting include:

- **Inventory Requirement:** Estimating the inventory needed to meet immediate demand.
- **Transport Facilities:** Providing transport facilities for the dispatch of finished goods.
- **Workload Management:** Deciding work loads for men and machines to ensure efficient operations.
- **Working Capital:** Determining the working capital needed for daily operations.
- **Production Run Setup:** Setting up production runs for the products.
- **Sales Quota:** Fixing sales quotas for the sales team.
- **Overtime Planning:** Finding the required overtime to meet delivery promises.

For example, a retail store might use short range forecasting to estimate the inventory needed for the upcoming holiday season, plan the work schedules for its employees, and determine the working capital required to stock up on popular items.

Qualitative Methods of Sales Forecasting

Question 2. What are the Qualitative Methods of demand Forecasting?

Alternative Questions

1. What are the different qualitative methods used for demand forecasting?
2. Explain the Survey of Buyer's Intention method in demand forecasting.
3. How does the Collective Opinion method work in demand forecasting?
4. Describe the Group Executive Judgment method for demand forecasting.
5. What is the Market Test method and when is it most appropriate to use?



Essay on Qualitative Methods of Demand Forecasting

Qualitative Methods of Demand Forecasting

Demand forecasting is a critical process for businesses to predict future sales and make informed decisions. Qualitative methods of demand forecasting rely on expert judgment and opinions rather than numerical data. These methods are particularly useful when historical data is unavailable or when forecasting new products. Here, we explore five key qualitative methods: Survey of Buyer's Intention, Collective Opinion, Group Executive Judgment, Expert's Opinion, and Market Test.

1. Survey of Buyer's Intention Method

This method involves directly contacting actual users of the product to ask about their future purchasing intentions. For example, a smartphone manufacturer might survey its customers to determine how many plan to buy the latest model within the next year. This method is most suitable for short-run forecasting as it provides immediate insights into customer intentions.

Example: A car manufacturer surveys its customers to find out how many plan to upgrade to a new model in the next six months. Based on the responses, the company can estimate the total sales for the upcoming period.

2. Collective Opinion or Sales Force Composite Method

In this method, the views of salesmen, branch managers, area managers, and sales managers are gathered. Salesmen, being close to the customers, provide estimates for their respective territories. These estimates are then consolidated and reviewed by higher management to account for factors like changes in product design or competition.

Example: A beverage company asks its sales team to estimate the expected sales in their regions. The sales manager then consolidates these estimates to forecast the total sales for the next quarter.

3. Group Executive Judgment Method

This method involves combining and averaging the opinions of top executives from different fields such as marketing, finance, and production. The collective judgment of these experts helps in making more accurate forecasts.

Example: A tech company's executives from various departments come together to forecast the demand for a new software product. Their combined expertise provides a comprehensive view of the market potential.

4. Expert's Opinion Method

Under this method, the organization collects opinions from specialists outside the organization. These experts might include industry analysts, trade journal editors, or professional consultants. Their insights help in making informed sales forecasts.

Example: A fashion retailer consults industry experts to predict the demand for its upcoming winter collection. The experts' opinions, based on market trends and consumer behavior, guide the retailer's production plans.

5. Market Test Method

This method involves selling the product in a part of the market for a certain period and then extrapolating the results to estimate the total market demand. It is particularly useful for new products or when reliable estimators are not available.

Example: A food company launches a new snack in a few cities to test its popularity. Based on the sales data from these test markets, the company forecasts the potential demand if the product is launched nationwide.

Mnemonic for Essay

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

"SCEGM" (pronounced "Sce-gem")

- **S:** Survey of Buyer's Intention
- **C:** Collective Opinion
- **E:** Expert's Opinion
- **G:** Group Executive Judgment
- **M:** Market Test

Facility Location

Alternative Essay Questions

1. Discuss the various factors that influence the decision-making process for selecting a business location.
2. How do socio-cultural and political issues impact the location selection for a new facility?
3. Explain the importance of environmental concerns and skilled labor availability in the location selection process.
4. Analyze the role of market proximity and cost considerations in determining the optimal location for a business.

Essay on Factors Influencing Location Selection Decision

Question 3. Main Essay Question

1. Discuss the various factors influencing location selection decisions in business operations. How do these factors contribute to strategic and operational success?

Alternative Replicative Essay Questions

2. Explain the importance of location selection in business strategy. Illustrate how sourcing, market proximity, cost, and environmental concerns affect this decision.
3. Evaluate the role of socio-cultural, political, and community factors in determining the ideal location for a business. Support your answer with examples.
4. Analyze how the availability of skilled labor and competitive pressure influence the selection of a business location.
5. How do operational efficiency and strategic benefits shape the location selection decision? Discuss with reference to logistics, inter-plant coordination, and profitability.

Factors Influencing Location Selection Decision

Selecting the right location for a business is a critical decision that can significantly impact its success. Various factors must be considered to ensure the chosen location aligns with the company's strategic goals and operational needs. These factors can be broadly categorized into sourcing, market proximity, cost, socio-cultural and political issues, environmental concerns, availability of skilled labor, and competitive pressure.

1. Sourcing

The availability of raw materials, natural resources, energy, and water is crucial for manufacturing and production facilities. For instance, a beverage company might choose a location near a water source to ensure a steady supply of this essential resource. Additionally, proximity to key suppliers and connectivity to alternate vendors can reduce transportation costs and improve supply chain efficiency. The opportunity for cross-docking and utilizing milk vans can further streamline logistics.

Example: A car manufacturer might select a location close to steel suppliers to minimize transportation costs and ensure timely delivery of raw materials.

2. Markets

Proximity to the market is essential for reducing transportation costs and ensuring quick delivery to customers. A location that covers a wide geographical area and is close to target customers can enhance market reach and customer satisfaction. Connectivity with a large customer base and lesser time to market are also critical considerations.

Example: An e-commerce company might establish a distribution centre near a major urban area to ensure fast delivery to a large customer base.

3. Cost

Cost considerations include transportation costs, lease or rental costs, taxes, and other hidden costs. A location with well-developed transportation infrastructure can reduce logistics expenses. Lower lease or rental costs can also make a location more attractive.

Example: A tech startup might choose a location in a city with lower rental costs to reduce overhead expenses and allocate more funds to research and development.

4. Socio-cultural, Community, and Political Issues

A supportive community, familiarity with local language and culture, and low crime rates are important for employee satisfaction and retention. The availability of prospective employees, quality of living, and access to medical facilities, fire, and police services are also crucial. Statutory and regulatory rules and regulations must be considered to ensure compliance.

Example: A multinational corporation might select a location in a city with a high quality of living and a supportive community to attract and retain top talent.

5. Environmental Concerns

Environmental factors such as air and water quality, waste disposal regulations, and the impact on local ecosystems must be considered. Companies are increasingly prioritizing sustainability and choosing locations that align with their environmental goals.

Example: A renewable energy company might choose a location with abundant sunlight or wind resources to optimize energy production.

6. Availability of Skilled Labour

The availability of skilled labour is essential for maintaining productivity and innovation. Companies often choose locations near educational institutions or in regions with a high concentration of skilled workers.

Example: A software development firm might establish an office in a city known for its tech talent and proximity to top universities.

7. Competitive Pressure

The presence of competitors can influence location decisions. Companies might choose locations that offer a competitive advantage, such as proximity to key markets or access to unique resources.

Example: A retail chain might open a store in a location with few competitors to capture a larger market share.

The location selection decision depends on various factors, including additional growth space, better transportation networks, reduced operational costs, a cordial labour situation, a better environment, improved community relations, greater inter-plant coordination, improved logistics, and increased future profitability.

mnemonic

"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)

Possible of way questions

Question 4.

1. What is plant layout and why is it important in production systems?
2. Describe the different types of plant layouts and their characteristics.
3. How does layout planning impact the flow of materials and people within a facility?
4. Explain the significance of grouping machines in different types of layouts.
5. What factors influence the choice of a particular layout type in a manufacturing facility?

Essay on Facility Layout

Question 5. What is facility Layout?. What are the different types of Layout?

Possible Replication Questions

1. What are the key differences between process layout and product layout?
2. How does a fixed position layout benefit the production of large, bulky products?
3. Explain the concept of mixed layout and its application in industrial establishments.
4. Describe the unique requirements of service facility layouts compared to manufacturing facility layouts.
5. How do different types of layouts impact the efficiency and flow of materials in a production system?

Facility Layout: Optimizing Efficiency and Flow

Facility layout, also known as plant layout, is a crucial aspect of manufacturing and production systems. It involves the strategic arrangement of departments, work-centers, equipment, and machinery to ensure a smooth flow of materials and work through the production process. Effective layout planning can significantly enhance productivity, reduce costs, and improve overall operational efficiency.

Understanding Facility Layout

Facility layout refers to the planning and positioning of all machines, equipment, utilities, workstations, customer service areas, material storage areas, tool servicing areas, tool cribs, aisles, restrooms, lunch rooms, coffee/tea bays, offices, and computer rooms. It also involves designing the patterns of flow for materials and people within and around the buildings. The primary goal is to create an efficient and effective physical arrangement of economic activity centers within a facility.

Essay on Facility Layout

Facility Layout: Enhancing Efficiency and Flow

Facility layout, also known as plant layout, is a critical aspect of manufacturing and service operations. It involves the strategic arrangement of departments, work-centers, equipment, and machinery to ensure a smooth flow of materials and work through the production process. Effective layout planning can significantly enhance productivity, reduce costs, and improve overall operational efficiency.

Types of Layouts

1. Process Layout (Functional Layout or Job Shop Layout)

In a process layout, similar machines are grouped together in one department based on their functions. This layout is ideal for facilities that handle a variety of products or services in small batches. For example, a hospital might use a process layout where departments like radiology, surgery, and emergency are grouped based on their functions.

Example: A custom furniture workshop arranges its layout so that all cutting machines are in one area, sanding machines in another, and assembly stations in yet another.

2. Product Layout (Straight-Line Layout or Layout for Serialized Manufacture)

A product layout arranges equipment and workstations in a linear sequence based on the production process. This layout is suitable for high-volume production of standardized products. For instance, an automobile assembly line where each station performs a specific task in the production of a car.

Example: A candy factory uses a product layout where ingredients are mixed, molded, cooled, and packaged in a continuous flow along a conveyor belt.

3. Fixed Position Layout (Static Layout)

In a fixed position layout, the product remains stationary, and workers, materials, and equipment are brought to the product. This layout is used for large, bulky, or heavy products that are difficult to move, such as ships or aircraft.

Example: An aircraft manufacturing plant where the plane remains in one location, and various teams and equipment move to the plane to perform their tasks.

4. Mixed Layout (Combined Layout)

A mixed layout integrates elements of both process and product layouts to meet specific production needs. This layout is often used in facilities that produce a variety of products with different production processes.

Example: A large manufacturing plant might use a combination layout where certain areas follow a product layout for high-volume items, while other areas use a process layout for custom orders.

5. Service Facility Layout

Service facility layouts are designed to bring together customers and services. These layouts should provide easy access from freeways and busy thoroughfares, large and well-organized parking areas, and well-designed walkways. Depending on the degree of customer contact, service facility layouts can be designed around customer receiving and servicing functions (such as banks) or around technologies and production efficiency (such as hospitals).

Example: A bank might have a layout that facilitates easy customer access to tellers and service desks, while a hospital might have a layout that optimizes the flow of patients through various medical departments.

Conclusion

Effective facility layout planning is essential for optimizing the flow of materials and people, reducing production costs, and enhancing overall efficiency. By carefully selecting and implementing the appropriate layout type, businesses can achieve significant improvements in their production processes and operational performance.

Resources Aggregate Planning

Possible Essay Questions

Question 6.

1. What is aggregate planning, and why is it important for managing production over an intermediate time horizon?
2. Discuss the various strategies used in aggregate planning to manage fluctuations in demand.
3. How does varying the size of the workforce impact the effectiveness of aggregate planning?
4. Explain the role of subcontracting in aggregate planning and provide examples of when it might be used.
5. Compare and contrast the different strategies of aggregate planning in terms of their advantages and disadvantages.

Essay on Aggregate Resources Planning

Aggregate Resources Planning: Balancing Demand and Capacity

Aggregate planning is a crucial intermediate-term planning decision that focuses on determining the quantity and timing of output over a period ranging from three months to one year. During this period, the physical facilities are assumed to be fixed, meaning that any fluctuations in demand must be managed by adjusting labor and inventory schedules. The primary goal of aggregate planning is to find the best combination of strategies to minimize costs while meeting demand.

Strategies for Aggregate Planning

1. Vary the Size of the Workforce

One of the primary strategies in aggregate planning is to adjust the size of the workforce in response to changes in demand. This involves hiring additional workers during periods of high demand and laying off workers when demand decreases. This strategy allows companies to align their labor force with production needs, ensuring that they can meet customer demand without incurring excessive labor costs.

Example: A retail company might hire seasonal workers during the holiday season to handle the increased demand for products and then reduce the workforce once the season ends.

2. Vary the Hours Worked

Another strategy is to maintain a stable workforce but adjust the number of hours worked. During periods of low demand, employees may experience idle time, while during peak demand, they may work overtime. This approach helps companies avoid the costs and disruptions associated with hiring and laying off workers.

Example: A manufacturing plant might implement overtime during peak production periods to meet increased demand without hiring additional staff.

3. Vary Inventory Levels

Adjusting inventory levels is another effective strategy for managing demand fluctuations. By building up inventory during periods of low demand, companies can ensure they have enough stock to meet increased demand when it arises. This strategy requires careful inventory management to avoid excess stock and associated holding costs.

Example: An electronics manufacturer might produce and store extra units of a popular product during off-peak seasons to ensure they can meet demand during the holiday shopping season.

4. Subcontracting

Subcontracting involves outsourcing production to external vendors when there is an upward shift in demand. This strategy allows companies to meet production requirements without investing in additional

capacity. Subcontracting can be particularly useful when demand is unpredictable or when a company lacks the resources to scale up production quickly.

Example: A clothing brand might subcontract production to a third-party manufacturer during a sudden surge in demand for a new fashion line.

Conclusion

Aggregate planning is essential for balancing demand and capacity over an intermediate time horizon. By employing strategies such as varying the workforce size, adjusting hours worked, managing inventory levels, and subcontracting, companies can effectively meet demand fluctuations while minimizing costs. Each strategy has its advantages and disadvantages, and the choice of strategy depends on the specific needs and circumstances of the business.

Essay on Material Requirement Planning (MRP-I)

Material Requirement Planning (MRP-I): Enhancing Production Efficiency

Question 7. Essay Questions on MRP-I

1. Discuss the four key objectives of MRP-I using the mnemonic "IRRI." How does each objective support operational excellence in a manufacturing setup?
2. Explain the concept of Material Requirement Planning (MRP-I) and discuss how it contributes to enhancing production efficiency in modern manufacturing.
3. Analyze how MRP-I helps in reducing inventory levels and manufacturing lead times. Support your answer with relevant industry examples.
4. How does MRP-I enable realistic delivery commitments and improve customer satisfaction? Illustrate with examples from different sectors.
5. "MRP-I is not just a planning tool—it's a strategic enabler." Critically evaluate this statement in the context of production coordination and efficiency.
6. Compare and contrast the role of MRP-I in a traditional manufacturing environment versus a modern, lean production system. What challenges and benefits arise in each context?

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. By focusing on the precise needs of production, MRP helps companies streamline their operations, reduce costs, and improve overall efficiency.

Objectives of MRP

1. Inventory Reduction

One of the primary objectives of MRP is to minimize inventory levels. By accurately determining how many components are required and when they are needed, MRP helps companies procure materials just in time for production. This approach prevents excessive buildup of inventory, reducing storage costs and minimizing the risk of obsolescence.

Example: A car manufacturer uses MRP to order specific quantities of tires and engines only when they are needed for assembly, avoiding the costs associated with storing large quantities of these components.

2. Reduction in Manufacturing and Delivery Lead Times

MRP plays a crucial role in identifying the quantities and timings of materials and components needed for production. By ensuring that all necessary materials are available when required, MRP helps avoid production delays and prioritizes production activities. This leads to shorter manufacturing and delivery lead times, allowing companies to meet customer deadlines more effectively.

Example: An electronics company uses MRP to schedule the delivery of circuit boards and other components, ensuring that production runs smoothly and products are delivered to customers on time.

3. Realistic Delivery Commitments

MRP provides production teams with accurate information about material availability and production schedules. This enables marketing and sales teams to make realistic delivery commitments to customers. By knowing exactly when products will be ready, companies can improve customer satisfaction and build trust.

Example: A furniture manufacturer uses MRP to inform its sales team about the expected delivery dates for custom orders, ensuring that customers receive their products as promised.

4. Increased Efficiency

MRP enhances efficiency by coordinating activities across various work centers. By ensuring a continuous flow of materials through the production line, MRP minimizes downtime and maximizes productivity. This close coordination helps companies achieve higher levels of operational efficiency.

Example: A pharmaceutical company uses MRP to synchronize the production of different drug components, ensuring that each stage of production is completed without delays.

Conclusion

Material Requirement Planning (MRP) is an essential tool for modern manufacturing. By focusing on inventory reduction, reducing lead times, ensuring realistic delivery commitments, and increasing efficiency, MRP helps companies optimize their production processes and meet customer demands effectively. Implementing MRP can lead to significant improvements in operational performance and cost savings.

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

Manufacturing Resources Planning (MRP-2)

Essay on Manufacturing Resource Planning (MRP II)

Question 8. Possible Essay Questions

1. How does Manufacturing Resource Planning (MRP II) enhance the planning and control of manufacturing processes?
2. Discuss the key components and functions integrated within MRP II systems.
3. Explain the universal applicability of MRP II to manufacturing organizations of different sizes and industries.
4. Compare and contrast MRP II with its predecessor, MRP I, highlighting the advancements and additional functionalities.

Manufacturing Resource Planning (MRP II): A Comprehensive Approach to Manufacturing Management

Manufacturing Resource Planning (MRP II) is an advanced system designed to help manufacturing managers effectively plan and control all aspects of the manufacturing process and its related support functions. Building on the foundation of Material Requirement Planning (MRP I), MRP II integrates additional data and functionalities, making it a comprehensive tool for managing manufacturing operations.

Key Components and Functions of MRP II

1. Materials Planning

MRP II ensures that the right materials are available at the right time to meet production schedules. By accurately forecasting material requirements, MRP II helps in reducing inventory costs and avoiding production delays.

Example: A car manufacturer uses MRP II to schedule the delivery of components like engines and tires, ensuring they arrive just in time for assembly.

2. Capacity Planning

MRP II includes capacity planning to ensure that the manufacturing facility can meet production demands. It takes into account the availability of machinery, labor, and other resources, allowing managers to optimize production schedules.

Example: An electronics company uses MRP II to plan the use of its assembly lines, ensuring that each line operates at optimal capacity without overloading any single resource.

3. Financial Planning

MRP II integrates financial data to provide a complete picture of the manufacturing process. This includes budgeting, cost control, and financial forecasting, helping managers make informed decisions about resource allocation.

Example: A pharmaceutical company uses MRP II to track production costs and forecast future expenses, ensuring that the manufacturing process stays within budget.

4. Engineering Integration

MRP II incorporates engineering data to ensure that production processes align with design specifications. This integration helps in maintaining product quality and consistency.

Example: An aerospace manufacturer uses MRP II to integrate engineering changes into the production schedule, ensuring that all components meet the latest design standards.

5. Sales and Marketing Coordination

MRP II provides valuable information to sales and marketing teams, helping them make realistic delivery commitments to customers. By aligning production schedules with sales forecasts, MRP II enhances customer satisfaction.

Example: A furniture manufacturer uses MRP II to inform its sales team about the expected delivery dates for custom orders, ensuring that customers receive accurate information.

Conclusion

Manufacturing Resource Planning (MRP II) is a powerful tool that enhances the planning and control of manufacturing processes. By integrating materials, capacity, financial, engineering, and sales data, MRP II provides a comprehensive approach to managing manufacturing operations. Its universal applicability makes it an essential system for manufacturing organizations of all sizes and industries.

Mnemonic for MRP II

To remember the key aspects of MRP II, you can use the mnemonic "MCFES":

- **M:** Materials planning
- **C:** Capacity planning
- **F:** Financial planning
- **E:** Engineering integration
- **S:** Sales and marketing coordination

QUESTIONS FROM PYP'S

Question 1.**(Dec 24 7M)**

METRO-WALLS ICE CREAM PARLOUR observed that during summer months the daily sales of its ice cream depends on the average day temperature as shown in the following Table:

Average Day Temperature in Centigrade (X)	20	25	30	35	40
Daily Sale of Ice Cream (in Thousand ₹) (Y)	10	20	30	40	50

Required:

- Fit a linear regression of Y on X.
- Estimate the trend values of daily sales of ice cream for average day temperature of 32 and 42 centigrade.
- Estimate the Average Day Temperature (in Centigrade) for the daily sale of ice cream of 160 thousands.

Answer:

Average Day Temperature in Centigrade (X)	Daily Sale of Ice Cream (in Thousand ₹) (Y)	Squares Average Day Temperature (X^2)	Product (XY)
20	10	400	200
25	20	625	500
30	30	900	900
35	40	1225	1400
40	50	1600	2000
$\Sigma X = 150$	$\Sigma Y = 150$	$\Sigma X^2 = 4750$	$\Sigma XY = 5000$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b we will have to solve the following equation:

$$\Sigma Y = na + b\Sigma X \dots\dots\dots (i)$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \dots\dots(ii)$$

By Putting values,

$$150 = 5a + 150b \dots\dots(iii)$$

$$5000 = 150a + 4750b \dots(iv)$$

By Multiplying eq (iii) by 30, we get.

$$4500 = 150a + 4500b \dots(v)$$

By subtracting eq. (v) from eq. (iv), we get

$$500 = 250b$$

$$= b = 500/250 = 2$$

By substituting the value of b in eq. (iii), we get

$$150 = 5a + 150 \times 2$$

$$= 150 - 300 = 5a$$

$$= -150 = 5a$$

$$= a = -150/5 = -30$$

Now putting the values of a and b the required regression equation of Y on X, is.

$$(i) Y = a + bX \text{ or } Y = -30 + 2X$$

$$(i) \text{ When Average Day Temperature in Centigrade (X) = 32}$$

$$\text{Daily Sale of Ice Cream (in Thousand ₹) (Y) = } a + bX$$

$$= -30 + 2 \times 32 = ₹34 \text{ (in thousands)}$$

When Average Day Temperature in Centigrade (X) = 42

Daily Sale of Ice Cream (in Thousand ₹) (Y) = $a + bX$

$$= -30 + 2 \times 42 = ₹54 \text{ (in thousands)}$$

(iii) When Daily Sale of Ice Cream (in Thousand ₹) (Y) = ₹ 60 (in thousands)

Average Day Temperature in Centigrade (X) =

$$Y = a + bX$$

$$60 = -30 + 2X$$

$$60 + 30 = 2X$$

$$90 = 2X$$

$$= X = 90/2 = 45 \text{ Centigrade}$$

Question 2.

(Dec 24 7M)

"The Plant Layout selected in conformity with Layout Principles should be an ideal one" - In this context, align those Plant Layout Principles

Answer:

Plant Layout- Principles:

The layout selected in conformity with layout principles should be an ideal one. These principles are:

- Principle of Minimum Travel: Men and materials should travel the shortest distance between operations so as to avoid waste of labour and time and minimise the cost of materials handling.
- Principle of Sequence: Machinery and operations should be arranged in a sequential order. This principle is best achieved in product layout, and efforts should be made to have it adopted in the process layout.
- Principle of Usage: Every unit of available space should be effectively utilised.
- Principle of Compactness: There should be a harmonious fusion of all the relevant factors so that the final layout looks well integrated and compact.
- Principle of Safety and Satisfaction: The layout should contain built in provisions for safety for the workmen. It should also be planned on the basis of the comfort and convenience of the workmen so that they feel satisfied.
- Principle of Flexibility: The layout should permit revisions with the least difficulty and at minimum cost.
- Principle of Minimum Investment: The layout should result in savings in fixed capital investment, not by avoiding installation of the necessary facilities but by an intensive, use of available facilities

Question 3.

(Jun 24 7M)

RONTEX Ltd., a medium size manufacturing Company has provided productions analysis of Coriander powder (in Lakh tonnes) for the years 2015 to 2023 as follows

Year	Productions of Coriander Powder (in Lakh Tonnes)
2015	54
2017	63
2019	69
2021	81
2023	48

(Present Calculation up to two decimal Points)

Required:

(i) Using the methods of least Squares Analyze a Straight line value.

(ii) Assess the estimated Production (in Lakh Tonnes) of Coriander Powder for the years 2014 and 2028.

Answer:

Years	Time Deviation from 2019 'X'	Production of Coriander Power (in lakh tonnes) 'Y'	X^2	XY
2015	-4	54	16	-216
2017	-2	63	4	-126
2019	0	69	0	0
2021	2	81	4	162
2023	4	48	16	192
n = 5	$\Sigma X = 0$	$\Sigma Y = 315$	$\Sigma X^2 = 40$	$\Sigma XY = 12$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b,

$$a = \Sigma Y / n = 315 / 5 = 63$$

$$b = \Sigma XY / \Sigma X^2 = 12 / 40 = 0.3$$

Hence,

- Straight line trend, $Y = 63 + 0.3X$
- The estimated Production (in Lakh Tonnes) of Coriander Powder for the years 2014 and 2028 is:

$$\text{In year 2014: } Y = 63 + 0.3(-5) = 61.5 \text{ Lakh Tonnes}$$

$$\text{In year 2028: } Y = 63 + 0.3(9) = 65.7 \text{ Lakh Tonnes}$$

Question 4.

(Dec 23 8M)

AS an Analyst of POXN Ltd., you are interested in studying whether some relationship does exist between the expenditure on Advertising and the Annual Sales. Accordingly the data of expenditure on Advertising and Sales are collected for past six years as follows:

Years	2017	2018	2019	2020	2021	2022
Expenditure on Advertising (X) (₹ in Crore)	1	2	4	3	10	4
Annual Sales (Y) (₹ in Crore)	18	23	32	28	38	29

Required:

(i) Fit a Linear Regression of Y on X.

(ii) Predict the annual sales when expenditure on Advertising is Rs. 5 Crore.

(iii) Estimate the expenditure on Advertising for annual sales of Rs. 42 Crore

Answer:

Years	Expenditure on Advt. (X) (₹ in crores)	Annual Sales (Y) (₹ in crores)	Squares of Exp. on Advt. X^2	Product XY
2017	1	18	1	18
2018	2	23	4	46
2019	4	32	16	128
2020	3	28	9	84
2021	10	38	100	380
2022	4	29	16	116
	$\Sigma X = 24$	$\Sigma Y = 168$	$\Sigma X^2 = 146$	$\Sigma XY = 772$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b we will have to solve the following equation:

$$\Sigma Y = na + b \Sigma X \dots (i)$$

$$\Sigma XY = a \Sigma x + b \Sigma X^2 \dots (ii)$$

By Putting values,

$$168 = 6a + 24b \dots (iii)$$

$$712 = 24a + 146b \dots (iv)$$

By Multiplying eq (iii) by 4, we get.

$$672 = 24a + 96b \dots (v)$$

By subtracting eq. (v) from eq. (iv), we get

$$100 = 50b$$

$$= b = 100/50 = 2$$

By substituting the value of b in eq. (iii), we get

$$168 = 6a + 24 \times 2$$

$$= 168 - 48 = 6a$$

$$= 120 = 6a$$

$$= a = 120/6 = 20$$

Now putting the values of a and b the required regression equation of Y on X, is.

$$(i) Y = a + bx \text{ or } Y = 20 + 2x$$

(i) When Expenditure on advt. (x) = ₹5 crore

$$\text{Annual sales (y)} = a + bx$$

$$= 20 + 2 \times 5 = 20 + 10 = ₹30 \text{ Crore}$$

(iii) When Annual Sales (y): ₹ 42 crore

Expenditure on advt. (x):

$$Y = a + bX$$

$$= 42 = 20 + 2X$$

$$= 42 - 20 = 2X$$

$$= 22 = 2X$$

$$= X = 22/2 = ₹11 \text{ crore}$$

Question 5.

(Dec 23 7M)

The following table gives the age of cars of SKODA Make and its Annual Maintenance cost.

Age of cars in years (X)	2	4	6	8
Maintenance cost (in thousand of Y)	10	20	25	30

Required:

(a) Fit a Linear Regression of Y on X

(b) Estimate: (i) Maintenance Cost for Age of Cars of 10 years

(ii) Age of car in years for Maintenance cost of Rs. 50000

Answer:

Age of cars in years (X)	Maintenance cost (₹ in thousand) (Y)	X^2	Y^2
2	10	4	20
4	20	16	80
6	25	36	150
8	30	64	240

$\Sigma X = 20$	$\Sigma Y = 85$	$\Sigma X^2 = 120$	$\Sigma Y^2 = 490$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b we will have to solve the following equation:

$$\Sigma Y = na + b\Sigma x \dots (i)$$

$$\Sigma XY = a\Sigma x + b\Sigma X^2$$

By Putting values,

$$85 = 4a + 20b \dots (iii)$$

$$490 = 20a + 120b \dots (iv)$$

By Multiplying eq (iii) by 5, we get.

$$425 = 20a + 100b \dots (v)$$

By subtracting eq. (v) from eq. (iv), we get

$$65 = 20b$$

$$b = 65/20 = 3.25$$

By substituting the value of b in eq. (iii), we get

$$85 = 4a + 20 \times 3.25$$

$$85 = 4a + 65$$

$$85 - 65 = 4a$$

$$20 = 4a = a = 20/4 = 5$$

Now putting the values of a and b the required regression equation of Y on X, is.

$$(i) Y = a + bx \text{ or } Y = 5 + 3.25x$$

(ii) When Age of cars (x) = 10 Years

$$\text{Maintenance Cost (y)} = a + bx$$

$$= 5 + 3.25 \times 10 = ₹ 37.5 \text{ (in thousand)}$$

(iii) when Maintenance Cost (y): ₹ 50 (in thousand)

Age of cars (x):

$$Y = a + bX$$

$$50 = 5 + 3.25X$$

$$50 - 5 = 3.25X$$

$$45 = 3.25X$$

$$X = 13.846 \text{ Years or 13 Years 10 Months (approx)}$$

Question 6.

(Jun 23 6M)

The sales of CCTV (rupees in million) of SONTON Ltd for the 5 years are given below:

Year	2014	2016	2018	2020	2022
Sales of CCTV (₹ in Millions)	18	21	23	27	16

Required:

Estimate the trend values of sales of CCTV for the years of 2021, 2024 and 2026

Answer:

Years	Time Deviation from 2018 'X'	Sales of CCTV (Rs. in Million) 'Y'	X^2	XY
2014	-4	18	16	-72
2016	-2	21	4	-42
2018	0	23	0	0
2020	2	27	4	54
2022	4	16	16	62

n=5	$\Sigma X=0$	$\Sigma Y=105$	$\Sigma X^2=40$	$2XY=4$

Regression equation of Y on X

$$Y=a+bX$$

To find the values of a and b,

$$a= Y/n = 105/5 = 21$$

$$b= XY/X\Sigma X^2 = 4/40 = 0.1$$

Hence,

- Straight line trend, $Y = 21 + 0.1X$
- Trend line value of Sales of CTV (Rs. in million) for the year 2021, 2024 & 2026:

$$\text{In year 2021: } Y = 21 + 0.1(3) = 21.3$$

$$\text{In year 2024: } Y = 21 + 0.1(6) = 21.6$$

$$\text{In year 2026: } Y = 21 + 0.1(8) = 21.8$$

Question 7.

(Jun 23 4M)

Discuss with appropriate examples, various properties of Aggregate Planning.

Answer:

Properties of Aggregate Planning:

To facilitate the production manager the aggregate planning must have the following characteristics:

- Both output and sales should be expressed in a logical overall unit of measuring. For example, an automobile manufacturing company can say 1000 vehicles per year, without giving the number of each variety of vehicle. Similarly a paint industry can say 10,000 liters of paint and does not mention the quantities of each variety of colour.
- Acceptable forecast for some reasonable planning period, say one year.
- A method of identification and fixing the relevant costs associated with the plant. Availability of alternatives for meeting the objective of the organisation. Ability to construct a model that will permit to take optimal or near optimal decisions for the sequence of planning periods in the planning horizon.
- Facilities that are considered fixed to carry out the objective

Question 8.

(Jun 23 8M)

The following table relates to the tourist arrivals in India during 2016 to 2022.

Year	2016	2017	2019	2021	2022
Tourist Arrivals (in Lakhs)	36	40	50	56	60

(Present calculation upto 3 decimal points)

Required:

- Fit a straight line trend by method of least squares.
- Estimate the number of tourists (in lakhs) in the year 2018 and that would arrive in the year 2026.

Answer:

Years	Time Deviation (X)	Tourist arrivals (in lakhs) (Y)	X^2	XY
2016	-3	36	9	-108
2017	-2	40	4	-80
2019	0	50	0	0
2021	2	56	4	112

2022	3	60	9	180
$n = 5$	$\Sigma X = 0$	$\Sigma Y = 242$	$\Sigma X^2 = 26$	$\Sigma XY = 104$

Regression equation of Y on X

$$Y = a + bX$$

To find the values of a and b,

$$a = Y/n = 242/5 = 48.4$$

$$b = \Sigma XY / \Sigma X^2 = 104/26 = 4$$

Hence,

1. Straight line trend, $Y = 48.4 + 4X$
2. The number of tourist (in lakh):
In year 2018: $Y = 48.4 + 4(-1) = 44.4$
In year 2026: $Y = 48.4 + 4(7) = 76.4$

Question 9.

(Jun 23 5M)

"The layout selected in conformity with layout principles should be an ideal one". In this context, state, what are the Principles for Plant layout (any five only)

Answer:

Plant Layout- Principles:

The layout selected in conformity with layout principles should be an ideal one. These principles are:

- Principle of Minimum Travel :Men and materials should travel the shortest distance between operations so as to avoid waste of labour and time and minimise the cost of materials handling.
- Principle of Sequence: Machinery and operations should be arranged in a sequential order. This principle is best achieved in product layout, and efforts should be made to have it adopted in the process layout.
- Principle of Usage: Every unit of available space should be effectively utilised.
- Principle of Compactness: There should be a harmonious fusion of all the relevant factors so that the final layout looks well integrated and compact.
- Principle of Safety and Satisfaction: The layout should contain built in provisions for safety for the workmen. It should also be planned on the basis of the comfort and convenience of the workmen so that they feel satisfied

Question 10.

The productions (in thousand tonnes) of a fertilizer factory of ROMY Ltd. for the year 2013 through 2022 are given below:

Year	2013	2015	2016	2017	2018	2019	2022
Production (in thousand tonnes)	70	75	90	98	85	91	100

(Present calculation upto three decimal points.)

Required.

- Fit a straight line by the method of least squares and tabulate the trend values.
- Estimate production (in thousand tonnes) of fertilizer in the year 2020 and year 2025

Answer:

- The equation of Straight line Trend is $Y = 86.55 + 3.146X$
- The estimated production (in Thousand Tones) for the year :
Year 2020= (Y) = 95.988
Year 2025=(Y) = 111.718



MODULE 3. DESIGNING OF OPERATIONAL SYSTEMS AND CONTROL

THEORY QUESTIONS

Student Hour Required - 5 Hour

Question 1.

1. Explain Importance of the concept Product Design?
2. Explain the role of product design in shaping customer perception and driving demand. Analyze how product design contributes to the efficiency and effectiveness of production systems.
3. Evaluate the strategic importance of product design in aligning with organizational goals and market competition.
4. Discuss the technical dimensions of product design and their impact on manufacturing feasibility.

Importance of Product Design

Product design is a crucial part of the marketing mix. Customers choose products that best meet their needs and provide them with the desired value. The features and quality of a product drive demand, which in turn supports the existence of value chains and organizations.

Importance of Product Design

1. Establishing Detailed Characteristics:

Product design helps define the core and additional features of a product to match market demand and competition.

Example: For a Royal Enfield bike, the core characteristics might include engine performance and fuel efficiency, while augmented features could be custom paint jobs and advanced navigation systems.

2. Providing Technical Requirements:

It sets the technical specifications needed for production processes.

Example: Designing a smartphone involves specifying the type of processor, screen size, and battery capacity.

3. Guiding Production System Design:

It offers a blueprint for setting up the production system.

Example: In car manufacturing, product design dictates the assembly line setup, including the sequence of operations and machinery required.

4. Supporting Production and Operations Strategy:

It gives direction to the overall production and operations strategy.

Example: A company like Apple uses product design to streamline its production processes, ensuring high quality and efficiency.

Activities and Responsibilities of Product Design

Question 2. What are the activities and Responsibilities of Product Design ?

1. Understand and Translate Customer Requirements:

Product design involves understanding the needs and preferences of customers (Voice of the Customers) and translating them into technical requirements (Voice of the Process) for design and execution planning.

Example: For a Royal Enfield bike, understanding customer preferences for a classic design with modern features and translating these into technical specifications for manufacturing.

2. Differentiate Existing Products:



Product design helps in differentiating existing products to extend their life cycle.

Example: Updating the design of a smartphone with new features like a better camera and improved battery life to keep it competitive in the market.

3. Developing New Products:

Creating new products to meet emerging market demands.

Example: Designing an electric version of a popular car model to cater to the growing demand for ecofriendly vehicles.

4. Providing Inputs for Quality Goals:

Offering necessary inputs to formulate quality goals for products.

Example: Setting quality standards for a new line of sports shoes to ensure durability and comfort.

5. Help in Cost Optimization:

Assisting in optimizing costs by designing products that are cost effective to produce.

Example: Redesigning a packaging process to use less material without compromising the product's integrity.

6. Building and Testing Model Prototypes:

Creating and testing prototypes to ensure the design meets all requirements.

Example: Building a prototype of a new laptop model and testing it for performance, durability, and user experience.

7. Documentation of Design Specifications:

Documenting all design specifications for future reference and production.

Example: Creating detailed design documents for a new kitchen appliance, including materials, dimensions, and assembly instructions.

Factors Affecting Product Design

Question 3. What are the factors affecting Product Design ?

1. True Understanding of Customer Needs:

Understanding both the stated and unstated needs of customers is crucial. Modern designers often use social media analytics to discover latent needs.

Example: A smartphone company analyzing social media trends to identify a demand for better battery life and incorporating it into their new models.

2. User Friendliness:

Products that are easy to use attract people from various demographic backgrounds.

Example: Designing a user friendly interface for a new app that can be easily navigated by both young and elderly users.

3. Balance Among Form, Function, and Cost:

Striking a balance between the product's appearance, features, and cost is essential.

Example: A car manufacturer balancing the sleek design, advanced features, and affordability of a new model.

4. Quality of Raw Materials:

The quality of raw materials or basic ingredients used in the product affects its overall quality.

Example: A chocolate manufacturer using high quality cocoa beans to ensure a premium product.

5. Selection/Design of Processes and Layouts:

The design of production processes and layouts impacts efficiency and product quality.

Example: An electronics company is designing an efficient assembly line to reduce production time and costs.



6. Quality and Condition of Machines/Instruments:

The condition of the machines and instruments used in the design process affects the final product.

Example: A textile company using state of the art weaving machines to produce high quality fabrics.

7. Capability and Maturity of Processes:

The capability and maturity of the processes used in production are crucial for consistent quality.

Example: A pharmaceutical company using well established processes to ensure the consistency and safety of its medications.

8. Skilled Resource Persons:

Having skilled personnel is essential for high quality product design and production.

Example: A fashion brand employing experienced designers to create innovative and stylish clothing.

9. Effect on Existing Products:

New product designs should consider their impact on existing products.

Example: A tech company ensuring that a new software update is compatible with older devices.

10. Presentation (Packaging):

The presentation and packaging of the product play a significant role in attracting customers.

Example: A cosmetics company using attractive and ecofriendly packaging to appeal to environmentally conscious consumers.

Characteristics of Good Product Design

Question 4.

1. What are the Characteristics of Good Product Design ?
2. Why is product quality important in product design?
3. How does reliability affect customer satisfaction?
4. What is the significance of designing a product at an optimum cost?
5. Why is a shorter design to market lead time beneficial?
6. How do aesthetics influence customer perception of a product?

A good product design must ensure the following:

1. Product Quality:

The product must satisfy the needs of the end customers while providing optimum value. The performance should meet expectations.

Example: A smartphone that offers highspeed performance, a long lasting battery, and a user friendly interface to meet customer needs.

2. Reliability:

The product must be reliable and worth paying for.

Example: A Royal Enfield bike known for its durability and consistent performance over time.

3. Optimum Cost:

The product must be designed at an optimum cost to be offered at an affordable price to the target customers.

Example: A budget friendly laptop that offers essential features without compromising on quality.

4. Shorter Design to Market Lead Time:

The product must have a shorter design to market lead time.

Example: A fashion brand quickly launching new clothing lines to keep up with seasonal trends.

5. Aesthetics:

The aesthetics or looks of the product must create an immediate impression in the minds of the customers.



Example: A sleek and stylish car design that attracts customers at first glance.

6. Compatibility and User Friendliness:

The product must be compatible, user friendly, and upgradable with the availability of after-sales support (e.g., spare parts).

Example: A modular smartphone that allows users to upgrade individual components like the camera or battery.

7. Maintainability and Reproducibility:

The product must be easily maintainable and reproducible.

Example: A home appliance that is easy to clean and has readily available replacement parts.

8. Balance Between Standardized and Customized Features:

The product should balance standardized basic features and customized augmented features.

Example: A customizable laptop where users can choose different specifications like RAM and storage.

9. Detailed Specification:

The product must have a detailed specification.

Example: A detailed user manual for a new software application outlining all features and functionalities.

10. Safety and Environmental Impact:

The product must be safe to use, errorproof, and should not harm the environment and users.

Example: An electric vehicle that meets all safety standards and has a minimal environmental footprint.

Process Decisions

Question 5.

1. Define and explain the different types of process decisions used in operations management.
2. Distinguish between Job Shop and Batch Process with suitable examples.
3. Evaluate the suitability of Repetitive and Continuous processes for mass production industries.
4. Discuss the strategic role of Project Process in managing large-scale, customized operations.
5. Analyze how process selection influences operational efficiency and customer satisfaction

1. Job Shop Process

A job shop process is used when a low volume of high variety goods is needed. Processing is intermittent, and each job requires different processing requirements. It is characterized by high customization (made to order), high flexibility of equipment, skilled labor, and low volume.

Example: A tool and die shop producing one of a kind tools.

Summary: Job shops are highly customizable, flexible, and suitable for low volume, high variety production.

2. Batch Process

Batch processing is used when a moderate volume of goods or services is required, along with a moderate variety in products or services. Volumes are higher because the same or similar products are repeatedly provided.

Example: Production of paint, ice cream, soft drinks, books, and magazines.

Summary: Batch processes handle moderate volumes and variety, producing goods in batches.

3. Repetitive Process

This process is used when higher volumes of more standardized goods or services are needed. It is characterized by slight flexibility of equipment and generally low labor skills. It includes production lines and assembly lines in mass production.

Example: Production of automobiles, home appliances, television sets, computers, and toys.



Summary: Repetitive processes are suitable for high volume, standardized production with minimal work in progress inventory.

4. Continuous Process

A continuous process is used when a highly standardized product is desired in high volumes. These systems have almost no variety in output and require no equipment flexibility. They are capital intensive and operate round the clock.

Example: Production of petroleum products, steel, sugar, flour, paper, cement, and fertilizers.

Summary: Continuous processes are for high volume, standardized production with rigid line flows.

5. Project Process

A project process is characterized by a high degree of job customization, large scope, and substantial resources. Projects are complex, take a long time, and consist of many complex activities.

Example: Building a shopping center, a dam, a bridge, constructing a factory, hospital, developing a new product, publishing a new book.

Summary: Project processes handle high customization and complexity, requiring significant resources and time.

Introduction to the Product Life Cycle

Question 6.

1. Explain the concept of the Product Life Cycle and its significance in strategic marketing and operations.
2. Compare and contrast the Introduction and Growth phases of the Product Life Cycle.
3. Evaluate the challenges faced by organizations during the Maturity phase and suggest strategies to sustain market relevance.
4. Discuss the strategic options available to firms during the Decline phase of the Product Life Cycle.
5. Illustrate how the Product Life Cycle influences pricing, promotional, and distribution decisions across its stages.

The PLC is typically represented as an S-shaped curve, illustrating the varying levels of sales and profitability over time. Understanding the PLC helps businesses strategize effectively at each stage to maximize the product's success and longevity.

1. Introduction Phase

During this phase, the product (either a completely new product or a new variant of an existing product) is introduced to the market for the first time. At this stage, the volume stays low, sales are low, and the effect of the learning curve is not realized. Hence, the return on investment is low.

This phase is characterized by a higher level of expenditure on promotional campaigns. The pricing depends on the innovativeness of the product, the nature of the target customer segment, and often discounts are given to entice potential customers.

Consumer Awareness: Low, as the product is new to the market.

Sales Volume: Low, as the product is just being introduced.

Price: Can vary; often higher due to innovation or lower to attract customers.

Profit: Low or negative due to high promotional costs.

Advertisement: High expenditure to create awareness.

Competition: Low, as the product is new.

Number of Participants: Few, as the market is just developing.



Summary: The introduction phase involves high promotional costs, low sales, and efforts to create consumer awareness.

2. Growth Phase

In this stage, the company focuses on rapid revenue generation and market growth. During this phase, product sales aim to cover fixed costs and reduce overhead costs while utilizing the learning from the previous stage. Promotional and advertising strategies are decided according to the level of growth. The objective is to retain existing customers and attract new ones.

Consumer Awareness: Increasing, as more people become aware of the product.

Sales Volume: Rapidly increasing.

Price: May decrease slightly due to competition but remains profitable.

Profit: Increasing as sales grow and costs are covered.

Advertisement: High, but more targeted to sustain growth.

Competition: Increasing, as more competitors enter the market.

Number of Participants: Growing, as the market expands.

Summary: The growth phase focuses on increasing sales, reducing costs, and expanding market presence.

3. Maturity Phase

This phase is characterized by market saturation. It is a critical phase for organizations. In the earlier stage (growth), the objective was to achieve fast growth, while in this stage, the company aims to flatten the curve to slow down the movement toward decline. Organizations often infuse variety and differentiation in products to start a new product life cycle (PLC) and find a niche market. At this stage, organizations engage in aggressive promotional and pricing programs. Profit margins are comparatively lower.

Consumer Awareness: High, as the product is well known.

Sales Volume: Peak, but growth slows down.

Price: Competitive pricing to maintain market share.

Profit: Stable but lower due to increased competition.

Advertisement: Aggressive to maintain market share.

Competition: High, as many competitors are present.

Number of Participants: Many, as the market is saturated.

Summary: The maturity phase involves maintaining market share, aggressive promotions, and stable but lower profits.

4. Decline Phase

After maturity, products start losing their attractiveness in the market, and sales decline. Profit margins become increasingly narrower. Organizations decide whether to scrap the product and focus on cost consolidation or come up with revival plans with product differentiation and promotional strategies to improve sales.

Consumer Awareness: High, but interest is declining.

Sales Volume: Decreasing.

Price: Lower to clear out inventory.

Profit: Declining, with narrow margins.

Advertisement: Reduced, focusing on clearing inventory.

Competition: Decreasing, as competitors exit the market.

Number of Participants: Few, as the market contracts.



Summary: The decline phase involves decreasing sales, reduced profits, and decisions on whether to discontinue or revive the product.

Replication Questions

Question 7.

1. What are the key characteristics of the introduction phase in the product life cycle?
2. How does the growth phase differ from the maturity phase in terms of sales volume and competition?
3. What strategies do companies use during the maturity phase to maintain market share?
4. What are the possible actions organizations can take during the decline phase?

Design Thinking

Question 8.

1. Explain the concept of Design Thinking and its relevance in solving complex business problems.
2. Describe the five stages of the Design Thinking process and analyze how each stage contributes to innovation.
3. Evaluate the role of empathy in Design Thinking and how it influences the success of product or service development.
4. Discuss the importance of prototyping and testing in Design Thinking. How do these stages reduce risk and improve final outcomes?
5. Compare Design Thinking with traditional problem-solving approaches in business. What makes Design Thinking more effective in dynamic environments?

Design thinking is a human centered approach to innovation that integrates the needs of people, the possibilities of technology, and the requirements for business success. It involves five key steps: Empathize, Define, Ideate, Prototype, and Test. This iterative process helps teams understand users, challenge assumptions, redefine problems, and create innovative solutions.

1. Empathize: Research Your Users' Needs

The first step in design thinking is to empathize with the users. This involves understanding their needs, experiences, and challenges through research methods such as interviews, observations, and surveys.

Case Study Example: Mahindra 6E EV Car

Mahindra's design team conducted extensive research to understand the needs and preferences of potential EV customers. They interviewed current car owners, observed their driving habits, and surveyed their concerns about electric vehicles. Key insights included the need for longer battery life, affordable pricing, and reliable charging infrastructure.

2. Define: State Your Users' Needs and Problems

In this stage, the team synthesizes the research findings to define the core problems and needs of the users. This step involves creating clear problem statements that guide the design process.

Case Study Example: Mahindra 6E EV Car

Based on the research, Mahindra defined the key problems: "Customers need an affordable EV with a long battery life and accessible charging stations." This clear problem statement helped the team focus on addressing these specific needs.

3. Ideate: Challenge Assumptions and Create Ideas

The ideation phase involves brainstorming and generating a wide range of ideas to solve the defined problems. The goal is to challenge assumptions and explore innovative solutions.



Case Study Example: Mahindra 6E EV Car

Mahindra's team brainstormed various ideas, such as developing a high capacity battery, partnering with charging station providers, and designing a cost effective manufacturing process. They also considered features like regenerative braking and smart navigation systems to enhance the user experience.

4. Prototype: Start to Create Solutions

In this stage, the team creates prototypes of the best ideas. Prototypes are scaled down versions of the product that allow the team to test and refine their concepts.

Case Study Example: Mahindra 6E EV Car

Mahindra developed several prototypes of the 6E EV car, each incorporating different features and technologies. They tested these prototypes to evaluate their performance, usability, and feasibility. Feedback from these tests helped refine the design and address any issues.

5. Test: Try Your Solutions Out

The final step is to test the prototypes with real users. This involves gathering feedback, identifying any problems, and making necessary adjustments to improve the product.

Case Study Example: Mahindra 6E EV Car

Mahindra conducted extensive testing of the 6E EV car with potential customers. They collected feedback on various aspects, such as battery life, charging convenience, and overall driving experience. Based on this feedback, they made final adjustments to ensure the car met customer expectations.



QUESTIONS FROM PYP'S

Question 1.**(Dec 24 7M)**

What is Design Thinking? Briefly discuss the five stages of Design Thinking

Answer:

Design thinking is a non-linear, iterative process that seeks to understand users needs, challenge assumptions, redefine problems and create innovative solutions to prototype and test. This involves five phases-Empathize, Define, Ideate, Prototype and Test-it is most useful to tackle problems that are ill-defined or unknown.

The Five Stages of Design Thinking

The Hasso Plattner Institute of Design at Stanford (aka the d.school) describes design thinking as a five-stage process. Note: These stages are not always sequential, and teams often run them in parallel, out of order and repeat them in an iterative fashion.

Stage 1: Empathize-Research Your Users Needs

Here, you should gain an empathetic understanding of the problem you're trying to solve, typically through user research. Empathy is crucial to a human-centered design process such as design thinking because it allows you to set aside your own assumptions about the world and gain real insight into users and their needs.

Stage 2: Define -State Your Users' Needs and Problems

It's time to accumulate the information gathered during the Empathize stage. You then analyze your observations and synthesize them to define the core problems you and your team have identified. These definitions are called problem statements. You can create personas to help keep your efforts human-centered before proceeding to ideation.

Stage 3: Ideate-Challenge Assumptions and Create Ideas

Now, you're ready to generate ideas. The solid background of knowledge from the first two phases means you can start to "think outside the box", look for alternative ways to view the problem and identify innovative solutions to the problem statement you've created. Brainstorming is particularly useful here...

Stage 4: Prototype-Start to Create Solutions

This is an experimental phase. The aim is to identify the best possible solution for each problem found. Your team should produce some inexpensive, scaled-down versions of the product (or specific features found within the product) to investigate the ideas you've generated. This could involve simply paper prototyping.

Stage 5: Test-Try Your Solutions Out

Evaluators rigorously test the prototypes. Although this is the final phase, design thinking is iterative: Teams often use the results to redefine one or more further problems. So, you can return to previous stages to make further iterations, alterations and refinements - to find or rule out alternative solutions. Overall, you should understand that these stages are different modes which contribute to the entire design project, rather than sequential steps. Your goal throughout is to gain the deepest understanding of the users and what their ideal solution/product would be

Question 2.**(Jun 24 7M)**

"Customers pay for the products that best fulfil their requirements and provide them the desired value". In this Context append the characteristics of a good product design.



Answer:

Characteristics of Good Product Design

A good product design must ensure the following:

- a) Product quality: The product must satisfy the needs of the end customers while providing optimum value. The performance should be at par with the expectations.
- b) The product must be reliable and worthy for paying for the same
- c) The product must be designed at an optimum cost to be offered at an affordable price to the target customers
- d) The product must be having a shorter design to market lead time
- e) The aesthetics/looks of the product must create an immediate impression in the minds of the customers
- f) The product must be compatible, user-friendly and upgradable with availability of after sales support (e.g., spare parts)
- g) The product must be easily maintainable and reproducible
- h) The product should balance between standardised basic features and customized augmented features
- i) A detailed specification
- j) The product must be safe to use, error proof and should not harm the environment and users

Question 3.

(Dec 23 6M)

"Virtually every good or service is made by using some variation of one of the three process strategies". In this context examine each of three process strategies.

Answer:

Three process strategies: Virtually every good or service is made by using some variation of one of three process strategies.

They are: (i) process focus (i) repetitive focus and (ii) product focus.

Each of these three strategies are discussed below:

(i) Process Focus:

Majority (about 75 per cent) of global production is devoted to low volume, high variety products in manufacturing facilities called job shops. Such facilities are organised around performing processes. For example, the processes might be welding, grinding or painting carried out in departments devoted to these processes. Such facilities are process focussed in terms of equipment, machines, layout and supervision. They provide a high degree of product flexibility as products move intermittently between processes. Each process is designed to perform a wide variety of activities and handle frequent changes. Such processes are called intermittent processes. These facilities have high variable costs and low utilisation of facilities.

(ii) Repetitive Focus

A repetitive process is a product oriented production process that uses modules. It falls between product focus and process focus. It uses modules which are parts or components prepared often in a continuous or mass production process. A good example of a repetitive process is the assembly line which is used for assembling automobiles and household appliances and is less flexible than process-focused facilities. Personal computer is an example of a repetitive process using modules in which the modules are assembled to get a custom product with the desired configuration.

**(iii) Product Focus:**

It is a facility organised around products, a product oriented, high-volume low-variety process. It is also referred to as a continuous process because it has very long continuous production run. Examples of product focussed processes are steel, glass, paper, electric bulbs, chemicals and pharmaceutical products, bolts and nuts etc. Product-focussed facilities need standardisation and effective quality control. The specialised nature of the facility requires high fixed cost, but low variable costs reward high facility utilization

Question 4.**(Dec 23 7M)**

You are working as a Production Manager in a Manufacturing unit. You are required to determine whether resources are to be organized around products or processes in order to implement the flow strategy. In this context, describe in brief the basic process types to be chosen. (any seven)

Answer:

The basic Process type to be chosen by the Production Manager are enumerated below :

1) Job shop process:

It is used in job shops when a low volume of high-variety goods are needed. Processing is intermittent, each job requires somewhat different processing requirements. A job shop is characterized by high customisation (made to order), high flexibility of equipment and skilled labour and low volume. A tool and die shop is an example of job shop, where job process is carried out to produce one - of - a kind of tools.

2) Batch process:

Batch processing is used when a moderate volume of goods or services is required and also a moderate variety in products or services. A batch process differs from the job process with respect to volume and variety in batch processing, volumes are higher because same or similar products or services are repeatedly provided, examples of products produced in batches include paint, ice cream, soft drinks, books and magazines.

3) Repetitive process:

This is used when higher volumes of more standardised goods or services are needed. This type of process is characterised by slight flexibility of equipment (as products are standardised) and generally low labour skills. Products produced include automobiles, home appliances, television sets, computers, toys etc. This kind of process is suitable to "manufacture-to- stock" strategy with standard products held in finished goods inventory. However, "assemble-to-order" strategy and "mass customisation" are also possible in repetitive process.

4) Continuous process:

This is used when a very highly standardised product is desired in high volumes. These systems have almost no variety in output and hence there is no need for equipment flexibility. A continuous process is the extreme end of high volume, standardised production with rigid line flows. Examples of products made in continuous process systems include petroleum products, steel, sugar, flour, paper, cement, fertilisers etc.

5) Project process:

It is characterised by high degree of job customisation, the large scope for each project and need for substantial resources to complete the project. Examples of projects are building a shopping centre, a dam, a bridge, construction of a factory, hospital, developing a new product, publishing a new book etc



Question 5.

(Jun 23 5M)

Enumerate, what are the factors influencing the product design of a product (any five).

Answer:

Factors Influencing Product Design

- i. Customer requirements: The designers must find out the exact requirements of the customers to ensure that the products suit the convenience of customers for use. The products must be designed to be used in all kinds of conditions.
- ii. Convenience of the operator or user: The industrial products such as machines and tools should be so designed that they are convenient and comfortable to operate or use.
- iii. Trade - off between function and form: The design should combine both performance and aesthetics or appearance with a proper balance between the two.
- iv. Types of materials used: Discovery of new and better materials can improve the product design. Designers keep in touch with the latest developments taking place in the field of materials and components and make use of improved materials and components in their product designs.
- v. Work methods and equipments: Designers must keep abreast of improvements in work methods, processes and equipments and design the products to make use of the latest technology and manufacturing processes to achieve reduction in costs.

Question 6.

(Jun 23 7M)

The Design Thinking can be thought of as a five stage process. Are these stages performed in a sequential order? Examine each stage of Design Thinking

Answer:

Design thinking is a non-linear, iterative process that seeks to understand users' needs, challenge assumptions, redefine problems and create innovative solutions to prototype and test. This involves five phases-Empathize, Define, Ideate, Prototype and Test-it is most useful to tackle problems that are ill-defined or unknown.

The Five Stages of Design Thinking

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Here, you should gain an empathetic understanding of the problem you're trying to solve, typically through user research. Empathy is crucial to a human-centered design process such as design thinking because it allows you to set aside your own assumptions about the world and gain real insight into users and their needs.

Stage 2: Define -State Your Users' Needs and Problems

It's time to accumulate the information gathered during the Empathize stage. You then analyze your observations and synthesize them to define the core problems you and your team have identified. These definitions are called problem statements. You can create personas to help keep your efforts human-centered before proceeding to ideation.

Stage 3: Ideate-Challenge Assumptions and Create Ideas

Now, you're ready to generate ideas. The solid background of knowledge from the first two phases means you can start to "think outside the box", look for alternative ways to view the problem and identify innovative solutions to the problem statement you've created. Brainstorming is particularly useful here.

**Stage 4: Prototype-Start to Create Solutions**

This is an experimental phase. The aim is to identify the best possible solution for each problem found. Your team should produce some inexpensive, scaled-down versions of the product (or specific features found within the product) to investigate the ideas you've generated. This could involve simply paper prototyping.

Stage 5: Test-Try Your Solutions Out

Evaluators rigorously test the prototypes. Although this is the final phase, design thinking is iterative: Teams often use the results to redefine one or more further problems. So, you can return to previous stages to make further iterations, alterations and refinements - to find or rule out alternative solutions. Overall, you should understand that these stages are different modes which contribute to the entire design project, rather than sequential steps. Your goal throughout is to gain the deepest understanding of the users and what their ideal solution/product would be

Question 7.**(Dec 22 7M)**

State in brief what are the characteristics of Good Product Design (any seven).

Answer:

The Characteristics of Good Product Design are stated below : (Any Seven)

- (i) **Function or performance:** The function or performance is what the customer expects the product to do to solve his/ her problem or offer certain benefits leading to satisfaction. For example, a customer for a motor bike expects the bike to start with a few kicks on the kick peddle and also expects some other functional aspects such as pick-up, maximum speed, engine power and fuel consumption etc.
- (ii) **Appearance or aesthetics :** This includes the style, colour, look, feel, etc. which appeals to the human sense and adds value to the product.
- (iii) **Reliability:** This refers to the length of time a product can be used before it fails. In other words, reliability is the probability that a product will function for a specific time period without failure.
- (iv) **Maintainability:** This refers to the restoration of a product once it has failed. High degree of maintainability is desired so that the product can be restored (repaired) to be used within a short time after it breaks down. This is also known as serviceability.
- (v) **Availability:** This refers to the continuity of service to the customer. A product is available for use when it is in an operational state. Availability is a combination of reliability and maintainability. High reliability and maintainability ensures high availability.
- (vi) **Productibility:** This refers to the ease of manufacture with minimum cost (economic production). This is ensured in product design by proper specification of tolerances, use of materials that can be easily processed and also use of economical processes and equipments to produce the product quickly and at a cheaper cost.
- (vii) **Simplification:** This refers to the elimination of the complex features so that the intended function is performed with reduced costs, higher quality or more customer satisfaction.
- (viii) **Standardisation:** This refers to the design activity that reduces variety among a group of products or parts. For example, group technology items have standardised design which calls for similar manufacturing process steps to be followed.
- (ix) **Specification:** A specification is a detailed description of a material, part or product, including physical measures such as dimensions, volume, weight, surface finish etc. These specifications indicate tolerances on physical measures which provide production department with precise



information about the characteristics of products to be produced and the processes and production equipments to be used to achieve the specified tolerances (acceptable variations).

- (x) Safety: The product must be safe to the user and should not cause any accident while using or should not cause any health hazard to the user. For example, a pharmaceutical product while used by the patient, should not cause some other side effect threatening the user

MODULE 4. PRODUCTION PLANNING AND CONTROL

4.4 Linear Programming Problem

Questions For Classroom Discussion

Question 1

A home resourceful decorator manufacturers two types of lamps, Say A and B. Both Lamps go through two technicians, first a cutter and second a finisher. Lamp A requires 2 hours of the cutter's time and one hour of finishers time. Lamp B requires 1 hour of cutter's time and 2 hour of finishers time each month. The cutter has 104 hours of available time and finisher has 76 hours of available time each month. Profit on the Lamp A is Rs 6 and on lamp B is Rs 11. Formulate Mathematical Model? (Formulate Linear Programming Model).

Question 2

A manufacturer of furniture makes two products, chairs and tables. Processing of these products is done on two machines A and B. A chair requires 2 hours on machine A and 6 hours on machine B. A table requires 5 hours on machine A and no time on machine B. Machine A has an available time of 16 hours and Machine B has an available time of 30 hour per day. Profit gained by the manufacturer from a chair is Rs 100 and from a table is Rs 500. Formulate the problem into a linear programming problem, the objective is to maximize the total profit.

Question 3

A firm can produce three types of clothes, say A,B,C. Three kinds of wool were required for it, say red wool, green wool and blue wool. One unit length of type A cloth needs 2 yards of red wool and 3 yards blue wool. One unit length of type B cloth needs 3 yards of red wool, 2 yards of green wool and 2 yards of blue wool. One unit of type C cloth needs 5 yards of green wool and 4 yards of blue wool. The firm has only a stock of 8 yards of red wool, 10 yards of green wool and 15 yards of blue wool. It is assumed that the income obtained from one unit length of Type A cloth is Rs 3, of type B cloth is Rs 5 and Type C cloth is Rs 4. Formulate LPP?

Question 4

A company produces two types of cow boy hats. Each hat of the first type requires twice as much labour as the second type. If all hats are of the second type only, the company can produce a total of 500 hats a day. The market limits daily sales of the first and second types to 150 and 250 hats. Assuming the profit per hat is Rs 8 for type 1 and Rs 5 for type 2. Formulate the problem as a linear programming model to determine the number of hats to be produced of each type so as to maximize the profit?

Question 5

An animal feed company must produce at least 200 kg's of a mixture consisting ingredients Coconut oil cake and Sesame Seeds oil cake. Coconut cake costs Rs 3 per kg and Sesame seeds cake cost Rs 8 per Kg. No more than 80 Kg's of coconut oil cake can be used and at least 60 Kg's of Sesame Seeds oil cake must be used. Formulate a mathematical model to the problem.

Question 6

A marketing manager wishes to allocate his annual advertising budget of Rs 2,000,000 in two media vehicles Griha Lakshmi and Vanitha. The unit cost of a message in Media Griha Lakshmi is Rs 100,000 and that of Vanitha is Rs 150,000. Media Griha Lakshmi is a monthly magazine and not more than one insertion is desired in one issue. At least 5 messages should appear in Vanitha. The expected effective audience for a unit message in Griha Lakshmi is 40,000 and that for Vanitha is 55000. Develop a mathematical Model

(Formulate linear programming problem)

Question 7

A manufacturer of a line patent medicines is preparing a production plan for medicines A and B. There are sufficient ingredients available to make 20,000 bottles of A and 40,000 bottles of B but there are only 45000 bottles into which either of the medicines can be put. Furthermore, it takes 3 hours to prepare enough materials to fill 1000 bottles of A, it takes one hour to prepare enough materials to fill 1000 bottles of B and there are 66 hours of available time for the operation. The Profit is Rs 8 per bottles for A and Rs 7 for B. Formulate this problem as a linear programming problem.

Advanced Questions

Question 1

Advanced Question

The agricultural research institute suggested to a farmer to spread out at least 4800 Kg, of Special Phosphate Fertilizer and not less than 7200 Kg of a Special Nitrogen fertilizer to raise productivity of crops in his fields. There are two sources for obtaining this, Mixture A and Mixture B. Both of these are available in bags weighing 100 Kg each and they cost Rs 40 and Rs 24 respectively. Mixture A contains Phosphate and Nitrogen equivalent of 20 Kg and 80 Kg respectively while Mixture B contains these ingredients equivalent of 50 Kg each. Formulate LPP in order to determine the number of bags, so that total cost is minimized ?

Different Methods of Solving LPP

- 1: Graphical Method
- 2: Simplex Method
- 3: Transportation Problem
- 4: Assignment Problem

Question 2

Advanced Question 6 Mark

A 24 hour super market has the following minimal requirement of cashiers.

Period	Time of the day	Minimum Number Required
1	3 to 7	7
2	7 to 11	20
3	11 to 15	14
4	15 to 19	20
5	19 to 23	10
6	23 to 03	5

Period 1 follows immediately after period 6. A cashier works eight consecutive hours, starting at the beginning of the six time periods. Determine a daily employee worksheet, which satisfies the requirements with least number of personnel. Formulate the problem as a linear programming problem.

A city hospital has the following minimal daily requirement for nurses:

Period	Time of the day	Number of nurses required
1	6 am to 10 am	2
2	10 am to 2 pm	7
3	2 pm to 6 pm	15
4	6 pm to 10 pm	8
5	10 pm to 2 am	20
6	2 am to 6 am	6

Nurses report to the hospital at the beginning of each period and work for consecutive 8 hours. The hospital wants to determine the minimal number of nurses to be employed so that there will be sufficient number of nurses available for each period. Formulate LPP. Do not solve.

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Question 3

Advance Question

An agriculturist has a 125 acre farm. He produces radish, Green peas and Potato. Whatever he raises is fully sold in the market. He gets Rs 5 for radish, Rs 4 for Green peas and Rs 5 for potato per kg. The average per acre yield is 1500 kg of radish, 1800 kg of green peas and 1200 kg of potato. To produce each 100 kg of radish and green peas and 80 kg of potato, a sum of Rs 12.50 has to be used for manure. Labour required for each acre to raise the crop is 6 man days for radish and potato each and 5 man days for green peas. A total of 500 man days of labor at a rate of Rs 40 per day available. Formulate LPP to maximize profit?

Question 4

Advanced Question

The marketing department of Everest company has collected information on the problem of advertising for its products.

This relates to the advertising media available, the number of families expected to be reached with each alternative, cost per advertisement, the maximum availability of each medium and expected exposure of each one .

The information is given below.

Advertising Media	Number of families Expected to cover	Cost per Advertisement	Maximum Availability	Expected Exposure
TV (30 Seconds)	3000	8000	8	80
Radio (15 Seconds)	7000	3000	30	20
Sunday Edition of Daily (Quarter Page)	5000	4000	4	50
Magazine (1 Page)	2000	3000	2	60

Other Information:

- Advertising budget is 70,000
- At least 40,000 families should be covered.
- At least 2 insertions be given in Sunday edition of daily but no more than 4 ads should be given on the TV.

Draft this as a linear programming model. The company's objective is to maximize the expected exposure.

Question 5

Advanced Question

A manufacturing firm needs 5 component parts. Due to inadequate resources, the firm is unable to manufacture all its requirements. Thus, the management is interested in determining as to how many, if

any, units of each component should be purchased from outside and how many should be produced internally. The relevant data are given here.

Components	Milling Hours	Assembly Hours	Per Unit Testing Hours	Total Requirements in Units	Price Per unit in the market	Per unit Cost
C1	4	1	15	20	48	30
C2	3	3	2	50	80	52
C3	1	1	0	45	24	18
C4	3	1	0.5	70	42	31
C5	2	0	0.5	40	28	16

Resources available are as follows

Milling Hours : 300 Hours

Assembly hours : 160 Hours

Testing Hours : 150 Hours

Formulate this as an LPP, taking objective function as maximization of saving by producing the components internally.

Question 6

Advanced Question

A leading chartered accountant is attempting to determine a best investment portfolio and is considering 6 alternative investment proposals. The following table indicates point estimates for the price per share, annual growth rate in the price per share, the annual dividend per share and a measure of risk associated with each investment.

Shares Under Consideration	A	B	C	D	E	F
Current Share Price	80	100	160	120	150	200
Projected Annual Growth Rate	0.08 or (8%)	0.07 or (7%)	0.10 or (10%)	0.12 or (12%)	0.09 or (9%)	0.15 or (15%)
Projected Annual Dividend Per Share	4	4.5	7.5	5.5	5.75	0
Projected Risk in Return	0.05	0.03	0.10	0.20	0.06	0.08

- Total amount available for investment is Rs 2,500,000 and the following conditions are to be satisfied
- The maximum rupee amount to be invested in alternative F is 250,000
- No more than 500,000 should be invested in alternatives A and B combined
- Total weighted risk should not be greater than 0.10 ,where

$$\text{Total weighted risk} = \frac{(\text{Amount invested in alternative} \times \text{Risk of alternative})}{\text{Total investment in alternative}}$$

- For the sake of diversity, at least 100 share is each stock should be purchased
- At least 10 percentage of total investment should be in alternatives A and B combined.
- Dividends for the year should be at least Rs 10,000.

Illustration From Study Material

Illustration 1:

A Chemical Company produces two compounds A and B. The following table gives the units of ingredients C and D per kg of compounds A and B as well as minimum requirements of C and D and costs/kg of A and B. Write down the problem mathematically for minimisation of cost.

		Table Compound		Minimum requirement
		A	B	
Ingredient	C	1	2	80
	D	3	1	75
Cost per kg.		4	6	

Answer:

Let x_1 be the no. of units of A

Let x_2 be the no. of units of B

Objective function: $\text{Min. } Z = 4x_1 + 6x_2$

Subject to Constraints:

$x_1 + 2x_2 \geq 8$ (Constraint on requirement of ingredient C)

$3x_1 + x_2 \geq 75$ (Constraint on requirement of ingredient D)

And $x_1, x_2 \geq 0$ (No negativity constraint)

Illustration 2:

A pension fund manager is considering investing in two shares A and B. It is estimated that:

- (i) Share A will earn a dividend of 12% per annum and share B 4% per annum.
- (ii) Growth in the market value in one year of share A will be 10 paise per Rs.1 invested and in B 40 paise per Rs.1 invested.

He requires investing the minimum total sum which will give:

Dividend income of at least Rs.600 per annum and growth in one year of at least Rs.1,000 on the initial investment.

You are required to:

State the mathematical formulation of the problem which will facilitate computation of the minimum sum to be invested to meet the manager's objective.

Answer:

Shares	Dividend	Growth in Rs.
A	12%	$10/100 = 0.1$
B	4%	$40/100 = 0.4$
Min-income	600	1000

Let x_1 be the amount invested on share A

Let x_2 be the amount invested on share B

Objective function: $\text{Min. } Z = x_1 + x_2$

Subject to constraints:

$0.12 x_1 + 0.04 x_2 \geq 600$ (Dividend income constraint)

$0.1 x_1 + 0.4 x_2 \geq 1000$ (Growth constraint)

And $x_1, x_2 \geq 0$. (Non negativity constraint)

Illustration 3:

A company possesses two manufacturing plants each of which can produce three products X, Y and Z from a common raw material. However, the proportions in which the products are produced are different in each plant and so are the plant's operating costs per hour. Data on production per hour costs are given below, together with current orders in hand for each product.

	Product			Operating cost/hour in Rs.
	X	Y	Z	
Plant A	2	4	3	9
Plant B	4	3	2	10
Orders on hand	50	24	60	

You are required to formulate the problem to find the number of production hours needed to fulfill the orders on hand at minimum cost.

Answer:

Let a be no. of hours of plant A in use

Let β be no. of hours of plant B in use

Objective function: $\text{Min } Z = 9a + 10\beta$

Subject to constraints:

$2a + 4\beta \geq 50$ (Constraint relating to Product X)

$4a + 3\beta \geq 24$ (Constraint relating to Product Y)

$3a + 2\beta \geq 60$ (Constraint relating to Product Z)

And $a, \beta \geq 0$ (Non negativity constraint)

Illustration 4:

The products P, Q and R are being produced in a plant having profit margin as Rs. 3, Rs. 5 and Rs. 4 respectively. The raw materials A, B and C are of scarce supply and the availability is limited to 8, 15 and 10 units respectively.

Specific consumption is indicated in the table below:

	P	Q	R	Available units
A	2	3	-	8
B	3	2	4	15
C	-	2	5	10
	3/-	5/-	4/-	

Write down the problem mathematically for maximization of profit margin.

Answer:

Let x_1 be the no. of units of product P

Let x_2 be the no. of units of product Q

Let x_3 be the no. of units of product R

Objective function: $\text{Max. } Z = 3x_1 + 5x_2 + 4x_3$

Subject to constraints:

$2x_1 + 3x_2 \leq 8$ (Constraint on availability of Raw Material 'A')

$3x_1 + 2x_2 + 4x_3 \leq 15$ (Constraint on availability of Raw Material 'B')

$2x_2 + 5x_3 \leq 10$ (Constraint on availability of Raw Material 'C')

And $x_1, x_2, x_3 \geq 0$ (Non negativity constraint)

Illustration 5:

A Bank is in the process of formulating its loan policy. Involving a maximum of Rs. 600 Million. Table below gives the relevant types of loans. Bad debts are not recoverable and produce no interest receive. To meet competition from other Banks the following policy guidelines have been set. At least 40% of the funds must be allocated to the agricultural and commercial loans. Funds allocated to housing must be at least 50% of all loans given to personal, car, Housing. The overall bad debts on all loans may not exceed 0.06.

Formulate a linear program Model to determine optimal loan allocations.

Type of loan	Interest rate %	Bad debts (Probability)
Personal	17	0.10
Car	14	0.07
Housing	11	0.05
Agricultural	10	0.08
Commercial	13	0.06

Answer:

Let x_1 be the amount allocated for personal loan

Let x_2 be the amount allocated for car loan

Let x_3 be the amount allocated for Housing loan

Let x_4 be the amount allocated for agricultural loan

Let x_5 be the amount allocated for Commercial loan

Objective Function: Max Z

$$= 0.17x_1 + 0.14x_2 + 0.11x_3 + 0.1x_4 + 0.13x_5 - (0.10x_1 + 0.07x_2 + 0.05x_3 + 0.08x_4 + 0.06x_5)$$

$$= (0.17 - 0.10)x_1 + (0.14 - 0.07)x_2 + (0.11 - 0.05)x_3 + (0.10 - 0.08)x_4 + (0.13 - 0.06)x_5$$

$$= 0.17x_1 + 0.07x_2 + 0.06x_3 + 0.02x_4 + 0.07x_5$$

Subject to constraints

(i) $x_1 + x_2 + x_3 + x_4 + x_5 \leq 600$ Millions (Constraint on total loan amount)

(ii) $x_4 + x_5 \geq 0.4 (x_1 + x_2 + x_3 + x_4 + x_5)$ (Constraint due to policy set for Agricultural and Commercial Loan)

(iii) $x_3 \geq 0.5 (x_1 + x_2 + x_3)$ (Constraint due to policy set for Housing Loan)

(iv) $0.1x_1 + 0.07x_2 + 0.05x_3 + 0.08x_4 + 0.06x_5 \leq 0.06$ Million (Constraint on limit of overall bad debt)

(v) $x_1, x_2, x_3, x_4, x_5 \geq 0$ (Non negativity constraint)

Illustration 6:

The annual hand-made furniture show and sales occurs next month and the school of vocational studies is planning to make furnitures for sale. There are three wood working classes - I year, II year, III year at the school and they have decided to make three styles of chairs A, B and C. Each chair must receive work in each class and the time in hours for each chair in each class is given.

Chair	I year	II year	III year
A	2	4	3
B	3	3	2
C	2	1	4

In the next month there will be 120 hours available in first year class, 160 hours in the second-year class and 100 hours in the third-year class to produce chairs. The teacher of the wood working class feels that a maximum of 40 chairs can be sold at the show. The teacher has determined that the profit from each type of chair will be A - Rs.40, B - Rs.35 and C - Rs.30.

Formulate a linear programming model to determine how many chairs should be produced to maximize profit.

Answer:

Let x_1 be the chairs produced of A type

x_2 be the chairs produced of B type

x_3 be the chairs produced of C type

Objective function

Maximise $Z = 40x_1 + 35x_2 + 30x_3$

Subject to constraints:

$2x_1 + 3x_2 + 2x_3 \leq 120$ (Constraint on available time of 1st year class)

$4x_1 + 3x_2 + x_3 \leq 160$ (Constraint on available time of 2nd year class)

$3x_1 + 2x_2 + 4x_3 \leq 100$ (Constraint on available time of 3rd year class)

$x_1, x_2, x_3 \geq 0$ (Non negativity constraint)

Illustration 7:

A company produces three products P, Q and R from three raw materials A, B and C. One unit of product P requires 2 units of A and 3 units of B. One unit of product Q requires 2 units of B and 5 units of C and one unit of product R requires 3 units of A, 2 units of B and 4 units of C. The company has 8 units of material A, 10 units of material B and 15 units of material C available to it. Profits per unit of products P, Q and R are Rs. 3, Rs. 5 and Rs.4 respectively.

Formulate the question mathematically to maximize the profit.

Answer:

DATA SUMMARY CHART

Decision variables	Products	Type of raw material			Profits per unit
		A	B	C	(Rs.)
x_1	P	2	3	-	3
x_2	Q	-	2	5	5
x_3	R	3	2	4	4
Units of material available:		8 Maximum	10 maximum	15 maximum	

x_1 = number of units of Product P

x_2 = number of units of Product Q

x_3 = number of units of Product R

The given Q is formulated as the LP model as follows:

Maximize $Z = 3x_1 + 5x_2 + 4x_3$

Subject to the constraints :

$2x_1 + 3x_3 \leq 8$ (Constraint due to availability of Material A)

$3x_1 + 2x_2 + 2x_3 \leq 10$ (Constraint due to availability of Material B)

$5x_2 + 4x_3 \leq 15$ (Constraint due to availability of Material C)

$x_1, x_2, x_3, \geq 0$ (Non negativity constraint)

Illustration 8:

A city hospital has the following minimal daily requirement for nurses:

Period	Clock time (24 hours day)	Minimal Number of Nurses Required
1	6 a.m. - 10 a.m.	2
2	10 a.m. - 2 p.m.	7
3	2 p.m. - 6 p.m.	75
4	6 p.m. - 10 p.m.	8
5	10 p.m. - 2 a.m.	20
6	2 a.m. - 6 a.m.	6

Nurses report to the hospital at the beginning of each period and work for 8 consecutive hours. The hospital wants to determine the minimal number of nurses to be employed so that there will be sufficient number of nurses available for each period.

Formulate this as a Linear Programming question by setting up appropriate constraints and objective function.

Answer:

$x_1 + x_3 \geq 15$, $x_3 + x_4 \geq 8$, $x_4 + x_5 \geq 20$, $x_5 + x_6 \geq 6$, and $x_6 + x_1 \geq 2$.

Since, the objective is to minimize the total number of nurses employed in the hospital,

$Z = x_1 + x_2 + x_3 + x_4 + x_5 + x_6$.

Obviously, we must have $x_1, x_2, x_3, x_4, x_5, x_6 \geq 0$.

Illustration 9:

A marketing manager wishes to allocate his annual advertising budget of Rs. 20,000 in two media vehicles A and B. The unit cost of a message in media A is Rs. 1,000 and that of B is Rs. 1,500. Media A is a monthly magazine and not more than one insertion is desired in one issue. At least 5 messages should appear in media B. The expected effective audience for unit messages in the media A is 40,000 and for media B is 55,000.

(i) Develop a mathematical model

Answer:

Step 1. The appropriate mathematical formulation of the given Q.... is as follows:

Maximize (total effective audience) $Z = 40,000 x_1 + 55,000 x_2$

Subject to the constraints

$1,000x_1 + 1,500x_2 \leq 20,000$ (Budget constraint)

$x_1 \leq 12$ (Constraint on annual no. of insertions in Media A)

$x_1 \geq 5$ or $-x_2 \leq -5$ (Constraint on annual no. of insertions in Media B)

$x_1, x_2 \geq 0$ (Non negativity constraint)

where

x_1 = annual number of insertions/messages for media A.

x_2 = annual number of insertions/ messages for media B.

Illustration 10:

One unit of product A contributes Rs. 7 and requires 3 units of raw material and 2 hours of labour. One unit of product B contributes Rs. 5 and requires one unit of raw material and one hour of labour. Availability of raw material at present is 48 units and hence there are 40 hours of labour.

i. Formulate it as a linear programming problem.

ii. Write its dual.

Answer:

i. The mathematical formulation of the linear programming problem is

$$\begin{aligned} \text{Maximise} \quad & Z = 7x_1 + 5x_2 \\ \text{Subject to} \quad & 3x_1 + x_2 \leq 48 \\ & 2x_1 + x_2 \leq 40 \\ & x_1, x_2 \geq 0 \end{aligned}$$

Where x_1 and x_2 denote the number of units of product A and B respectively.

ii. The dual of the above problem is:

$$\begin{aligned} \text{Minimize} \quad & Z^* = 48y_1 + 40y_2 \\ & 3y_1 + 2y_2 \geq 7 \\ & y_1 + y_2 \geq 5 \\ & y_1, y_2 \geq 0 \end{aligned}$$

Where y_1 and y_2 are the dual variables indicating the shadow prices of raw material and labour respectively

Illustration 11:

A Company produces the products P, Q and R from three raw materials A, B and C. One unit of product P requires 2 units of A and 3 units of B. A unit of product Q requires 2 units of B and 5 units of C and one unit of product R requires 3 units of A, 2 unit of B and 4 units of C. The Company has 8 units of material A, 10 units of B and 15 units of C available to it. Profits/unit of products P, Q and R are Rs.3, Rs.5 and Rs.4 respectively.

(a) Formulate the problem mathematically,

(b) Write the Dual problem.

Answer:

Raw Materials	x1	x2	x3	Available units
	P	Q	R	
A	2	-	3	8
B	3	2	2	10
C	-	5	4	15
	3	5	4	

Profits 3/- 5/- 4/-

Let x_1 be the no. of units of P

Let x_2 be the no. of units of Q

Let x_3 be the no. of units of R

Objective function: Max. $Z = 3x_1 + 5x_2 + 4x_3$

Subject to constraints:

$2x_1 + 3x_2 \leq 8$ (Constraint on availability of Raw Material 'A')

$3x_1 + 2x_2 + 2x_3 \leq 10$ (Constraint on availability of Raw Material 'B')

$5x_2 + 4x_3 \leq 15$ (Constraint on availability of Raw Material 'C')

And $x_1, x_2, x_3 \geq 0$. (Non negativity constraint)

Primal

Max. $Z = 3x_1 + 5x_2 + 4x_3$

Subject to

$$2x_1 + 3x_2 \leq 8$$

$$3x_1 + 2x_2 + 2x_3 \leq 10$$

$$5x_2 + 4x_3 \leq 15$$

$$\text{And } x_1, x_2, x_3 \geq 0$$

Dual

$$\text{Min. } Z = 8y_1 + 10y_2 + 15y_3$$

Subject to

$$2y_1 + 3y_2 \geq 3$$

$$3y_1 + 2y_2 + 5y_3 \geq 5$$

$$2y_2 + 4y_3 \geq 4$$

$$\text{And } y_1, y_2, y_3 \geq 0$$

$$2x_1 + 3x_2 + S_1 = 8$$

$$3x_1 + 2x_2 + 2x_3 + S_2 = 10$$

$$5x_2 + 4x_3 + S_3 = 15$$

$$\text{Max } Z = 3x_1 + 5x_2 + 4x_3 + 0.S_1 + 0.S_2 + 0.S_3$$

$$\therefore x_1 = 23/20 \quad x_2 = 19/10 \quad x_3 = 11/8$$

$$Z = 18.45$$

Illustration 12:

Four Products A, B, C and D have Rs. 5, Rs. 7, Rs. 3 and Rs. 9 profitability respectively. First type of material (limited supply of 800 kgs.) is required by A, B, C and D at 4 kgs., 3 kgs, 8 kgs, and 2 kgs. respectively per unit.

Second type of material has a limited supply of 300 kgs. and is for A, B, C and D at 1 kg, 2 kgs, 0 kgs, and 1 kg per unit. Supply of the other type of materials consumed is not limited. Machine hrs. available are 500 hours and the requirements are 8,5,0 and 4 hours for A, B, C and D each per unit.

Labour hours are limited to 900 hours and requirements are 3,2,1 and 5 hours for A, B, C and D respectively.

How should the firm approach so as to maximize its profitability? Formulate this as a linear programming problem. You are not required to solve the LPP.

Answer:

Let x_1 be the no. of units of product A

Let x_2 be the no. of units of product B

Let x_3 be the no. of units of product C

Let x_4 be the no. of units of product D

Objective function Maximize $Z = 5x_1 + 7x_2 + 3x_3 + 9x_4$

	A	B	C	D	Supply in Kgs.
I type material	4	3	8	2	800
II type material	1	2	0	1	300
Machine	8	5	0	4	500
Labour	3	2	1	5	900
Profit	5	7	3	9	

Subject to constraints

$$4x_1 + 3x_2 + 8x_3 + 2x_4 \leq 800 \text{ (Constraint on availability of Material type I)}$$

$$x_1 + 2x_2 + 0.x_3 + x_4 \leq 300 \text{ (Constraint on availability of Material type II)}$$

$$8x_1 + 5x_2 + 0.x_3 + 4x_4 \leq 500 \text{ (Constraint on Machine Hours available)}$$

$3x_1 + 2x_2 + x_3 + 5x_4 \leq 900$ (Constraint on Labour Hours available)

and $x_1, x_2, x_3, x_4 \geq 0$. (Non negativity constraint)

Illustration 13:

Mutual Fund has cash resources of Rs. 200 million for investment in a diversified portfolio. Table below shows the opportunities available, their estimated annual yields, risk factor and term period details.

Formulate a Linear Program Model to find the optimal portfolio that will maximize return, considering the following policy guidelines:

- All the funds available may be invested
- Weighted average period of at least five years as planning horizon.
- Weighted average risk factor not to exceed 0.20.
- Investment in real estate and speculative stocks to be not more than 25% of the monies invested in total.

Investment type	Annual yield (percentage)	Risk factor	Term period (years)
Bank deposit	9.5	0.02	6
Treasury notes	8.5	0.01	4
Corporate deposit	12.0	0.08	3
Blue-chip stock	15.0	0.25	5
Speculative stocks	32.5	0.45	3
Real estate	35.0	0.40	10

Answer:

Let x_1, x_2, x_3, x_4, x_5 and x_6 represent the six different investment alternatives, i.e., x_1 is bank deposit, x_2 is treasury note, x_3 corporate deposit, x_4 blue chip stock, x_5 speculative stock and x_6 real estate. The objective is to maximize the annual yield of the investors (in number of units) given by the linear expression.

Maximize $Z = 9.5x_1 + 8.5x_2 + 12.0x_3 + 15.0x_4 + 32.5x_5 + 35.0x_6$

Subject to the Constraints:

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \leq 1$ (Investment decision)

$0.02x_1 + 0.01x_2 + 0.08x_3 + 0.25x_4 + 0.45x_5 + 0.40x_6 \leq 0.20$ (Constraint on weighted average risk of the portfolio)

$6x_1 + 4x_2 + 3x_3 + 5x_4 + 3x_5 + 10x_6 \geq 5$ (Constraint on weighted average length of period of investment)

$x_5 + x_6 \leq 0.25$ (Constraint on investment in real estate and speculated stock)

$x_1, x_2, x_3, x_4, x_5, x_6 \geq 0$ (non-negativity condition)

Illustration 14:

What is the slope of the objective function $\text{Max } Z = 15X + 45Y$?

Answer:

The slope form is $Y = mX + b$ where $m = \text{slope}$

Rearranging,

$45Y = -15X + Z$

$Y = \frac{15x}{45} + \frac{z}{45}$

Slope is $-15/45$ or $-1/3$.



Illustration 15:

An electronic goods manufacture has distributors who will accept shipments of either transistor radios or electronic calculators to stock for Christmas inventory. Whereas the radios contribute Rs.10 per unit and the calculator Rs.15 per unit to profits, both products use some of the same components. Each radio requires each of diodes and resistors, while each calculator requires 10 diodes and 2 resistors. The radio take 12.0 minutes and the calculators take 9.6 minutes of time on the company's electronic testing machine, and the production manager estimates that 160 hours of test time is available. The firm has 8,000 diodes and 3,000 resistors in inventory. What product of mix of products should be selected to obtain the highest profit?

Answer:

The decision variables are radios, R , and calculators, C , and we must determine how many of each should be produced to maximize profit, Z .

(1) Objective function

$$\text{Max } Z = 10R + 15C$$

Constraints

Diodes (8,000 available): Radios require 4 each, and calculators require 10 each.

$$\therefore 4R + 10C \leq 8,000$$

Resistors (3,000 available): Radios require 4 each, and calculators require 2 each.

$$\therefore 4R + 2C \leq 3,000$$

Testing (9,600 minutes available): Radios require 12.0 minutes, and calculators require 9.6 minutes.

$$12R + 9.6C \leq 9,600$$

(2) Graph 'bf variables and constraints

Plotting each of the constraints inequality as an equality, we have:

$$\text{For Diodes: } 4R + 10C = 8,000$$

$$\text{If } R = 0, \text{ then } C = 800$$

$$\text{If } C = 0, \text{ then } R = 2,000$$

$$\text{For Resistors: } 4R + 2C = 3,000$$

$$\text{If } R = 0, \text{ then } C = 1,500$$

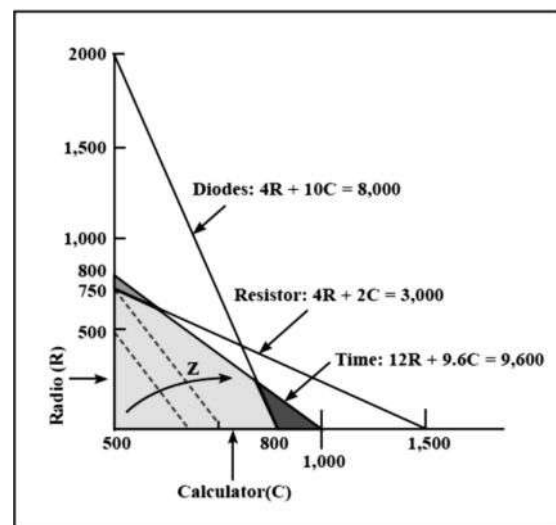
$$\text{If } C = 0, \text{ then } R = 750$$

$$\text{For Testing: } 12R + 9.6C = 9,600$$

$$\text{If } R = 0, \text{ then } C = 1,000$$

$$\text{If } C = 0, \text{ then } R = 800$$

Note: The resulting graph establishes a feasible region bounded by the time, diode, and resistor constraints that $R \geq 0$ and $C \geq 0$.



(3) Slope of the objective function.

We can express our objective function in slope intercept form, where the Y axis corresponds to R and the X axis to C .

$$Z = 10R + 15C$$

$$\text{Or, } 10R = -15C + Z$$

$$\therefore R = \frac{15}{10}C + \frac{Z}{10} = \frac{3}{2}C + \frac{Z}{10}$$

$\therefore$ Slope = $-3/2$, which means that for every 3-unit decrease in Y there is a 2 increase in X. This slope is plotted as a dotted line in the graph by marking off 3 units (negative) in R for each 2 units (positive) in C .



- (4) Move objective function to optimize. The slope of the objective function (to objective line) is moved away from the origin until constrained. In this case the binding constraints are the diode inventory supply and testing machine time availability.
- (5) Read solution values. The arrows point to the approximate R and C coordinates of the constraining intersection.

Number of radios = 240

Number of calculators = 700

Note: That the simultaneous solution of the two binding constraint equations would lend more accuracy to the answer:

$$(4R + 10C = 8,000) \times (-3) = -12R - 30C = -24,000$$

$$\underline{12R + 9.6C = 9,600}$$

$$-20.4C = -14,400$$

$$C = 705 \text{ calculators}$$

Substituting to solve for R:

$$4R + 10(705) = 8,000$$

$$\therefore R = 8,000 - 7,050 / 4 = 237 \text{ radios}$$

Comment: We had two decision variables (that is, products) to choose from and established a profit function, Z, and constraints and optimized the function by moving it away from the origin. The graph of this example showed that the resistor supply was not constraining, so only two constraints (diodes and test time) were binding. Similarly, there were two decision variables in the solution, that is, we ended up producing both radios and calculators. The number of variables in solution will always equal the number of explicit constraints that are binding.

The graphic linear programming solution gives an indication of the sensitivity of the solution to changes in the constraints. If for example, additional diodes could be purchased from an outside supplier with no increase in cost, profit would be maximized by extending the iso - objective line to the next corner and producing 1,000 calculators and no radios. In this case we would have one explicit constraint (time) binding and only one decision variables (calculators) in the final solution.

Illustration 16:

The simplex calculator company makes a profit of Rs.5 on each model X and Rs.20 on each model Y. Each calculator requires the following time (in minutes) on the cleaning and testing machines.

	X Requirements	Y Requirements	Time Available
Cleaning	2	4	10
Testing	6	3	12

- (a) State the objective function and constraints.
 (b) Arrange the equations in a simplex format.

Answer:

(a) Objective function $\text{Max } Z = 5X + 20Y$

Constraints:

Cleaning $2X + 4Y \leq 10$

Testing $6X + 3Y \leq 12$

(b)

C → ↓ Variables in solution		5	20	0	0	Solution Values (RHS)
		Decision variables				
		X	Y	S ₁	S ₂	
0	S ₁	2	4	1	0	10
0	S ₂	6	3	0	1	12
	Z	0	0	0	0	0
	C-Z	5	20	0	0	

Illustration 17:

The initial matrix of a maximization linear programming problem is as shown where the decision variables are designated A, B, etc.

C → ↓		4	8	6	0	0	0	RHS
	Variables in solution							
		5	9	0	1	0	0	36
		0	8	5	0	1	0	24
		2	0	5	0	0	1	7
		0	0	0	0	0	0	
		4	8	6	0	0	0	0

(a) State the original constraint equations.

(b) How many decision variables are there?

(c) State the objective function.

Answer:

(a) $5A + 9B \leq 36$, $8B + 5C \leq 24$, and $2A + 5C \leq 7$

(b) Three

(c) $\text{Max } Z = 4A + 8B + 6C$

4.5 Transportation Problem

Questions For Classroom Discussion

Question 1

Find basic feasible (Initial Solution) solution to the transportation problem?

Answer 1: Solve through Northwest Corner Rule Method

Answer 2: Solve through Lowest Cost Entry Method

Answer 3: Solve through Vogel's Approximation Method (Penalty Method)

Question 2

Find optimal solution to the transportation Problem?

Answer

Step 1: Find basic feasible solution through Vogel's Approximation method.

Step 2: Find optimal solution through Modified Distribution Method. (MODI's Method) or (U-V) Method.

Question 3

Needline Exporters is a Tirurangadi-based textile firm exporting textile items to Dubai, New York, and Manama City from its four factories located in Madhura, Ahmedabad, Sivakasi, and Chennai. The firm has received the following requirements:

He got a requirement of 7000, 9000 and 18000 from Dubai, New York and Manama city respectively.

The Quantity available at Madhura, Ahmedabad, Sivakasi and Chennai are 5000, 7000, 8000, and 14000 respectively.

The per unit cost of transportation from different origins to destinations are given in the table below.

Find basic feasible solution to the transportation problem through North West Corner Rule Method .

Origin/Destination	Dubai	New York	Manama	Supply
Madhura	2	7	4	5000
Ahmedabad	3	3	1	7000
Sivakasi	5	4	7	8000
Chennai	1	6	2	14000
Demand	7000	9000	18000	34000

Question 4

Solve the following transportation problem, through North West Corner Rule Method

Factory/Warehouse	W1	W2	W3	W4	W5	Supply
F1	3	4	6	8	9	20
F2	2	10	1	5	8	30
F3	7	11	20	40	3	15
F4	2	1	9	14	16	13
Demand	40	6	8	18	6	78

Question 5

Home Work Question (Previous Year Question)

Solve the following transportation problem, through Northwest corner rule

Plant\ Warehouse	W1	W2	W3	W4	Supply
P1	190	300	500	100	70



P2	700	300	400	600	90
P3	400	100	600	200	180
Demand	50	80	70	140	

Lowest cost Entry Method and Vogels Approximation Method

The above questions are solved using the following methods:

1. Least Cost Entry Method
2. Vogel's Approximation Method (Penalty Method)

Modified Distribution Method- (MODI's Method) or (U-V) Method

Find optimal solution to the transportation from the basic feasible solution.

	W1	W2	W3	W4	W5	Demand
F1	3 ^[20]	4	6	8	9	20
F2	4 ^[4]	10	1 ^[8]	5 ^[18]	8	30
F3	7 ^[9]	11	20	40	3 ^[6]	15
F4	2 ^[7]	1 ^[6]	9	14	16	13
Supply	40	6	8	18	6	78

Question 6

Practice Question

Find optimal solution to the Transportation Problem from the basic feasible solution.

	W1	W2	W3	Supply
F1	2 ^[5]	7	4	5
F2	3	3 ^[2]	1 ^[6]	8
F3	5	4 ^[7]	7	7
F4	1 ^[2]	6	2 ^[12]	14
Demand	7	9	18	34

Unbalanced Transportation Problem

Unbalanced Transportation Problems

Transportation problems are considered unbalanced when:

1. Supply is greater than demand
2. Demand is greater than Supply

Question 7

Find basic feasible solution to the transportation problem? Which Factories items are unsold?

	W1	W2	W3	W4	Supply
F1	11	20	7	8	50
F2	21	16	10	12	40
F3	8	12	18	9	70
Demand	30	25	35	40	130\160

Maximization of the Transportation Problem

Question 8

Solve the following maximization of Transportation Problem?

	W1	W2	W3	W4	Supply
F1	15	51	42	33	23

F2	80	42	26	81	44
F3	90	40	66	60	33
Demand	23	31	16	30	100

Mathematical Formulation of LPP

Formulate LPP to the minimization problem

	W1	W2	W3	Supply
F1	3	5	8	25
F2	8	9	10	35
F3	4	7	9	40
Demand	20	30	50	100

Mathematical Formulation of LPP (Unbalanced)

Formulate LPP to the minimization problem

	W1	W2	W3	Supply
F1	3	5	8	25
F2	8	9	10	35
F3	4	7	9	40
Demand	20	30	60	110\100

Question 9

Homework - Previous Year Question (2007, June 3(a))

The following table shows all the necessary information on the availability of supply to each factory of Agro Industries Ltd, the requirement of each destination and the unit of transport cost from each factory to each destination

	W1	W2	W3	Supply
A	5	1	7	10
B	6	4	6	80
C	3	2	5	15
Demand	75	20	50	145\105

Since there is not enough supply, some of the demand at three destination may not be satisfied. For the unsatisfied demands, penalty costs be Re 1, 2 and 3 respectively.

Find the optimal allocation that minimize the transportation and penalty costs by using the Vogel's Approximation Method (VAM) (10 Marks)

Optimal Answer is 555

Illustration From Study Material

Illustration 18:

The cost conscious company requires for the next month 300, 260 and 180 tonnes of stone chips for its three constructions C1, C2 and C3 respectively. Stone chips are produced by the company at three mineral fields taken on short lease by the company. All the available boulders must be crushed into chips. Any excess chips over the demands at sites C1, C2 and C3 will be sold ex-fields.

The fields are M1, M2 and M3 which will yield 250, 320 and 280 tons of stone chips respectively.

Transportation costs from mineral fields to construction sites vary according to distances, which are given below in monetary unit (MU).

	To	C1	C2	C3
From	M1	8	7	6
	M2	5	4	9
	M3	7	5	5

(i) Determine the optimal economic transportation plan for the company and the overall transportation cost in MU.

(ii) What are the quantities to be sold from M1, M2 and M3 respectively?

Answer:

(i) **Table: 1 Cost Matrix**

From \ To	C ₁	C ₂	C ₃	Supply
M ₁	8	7	6	250
M ₂	5	4	9	320
M ₃	7	5	5	280
Demand	300	260	180	850
				750

From the given data we have Total Supply = 850 tonnes and total Demand = 740 tonnes i.e., Supply $\neq$ Demand.

So this is an unbalanced problem of transportation. To make it balanced we introduce a "Dummy" construction site of demand $850 - 740 = 110$ tonnes and having zero cost elements for all the cells of the matrix corresponding to it.

Table: 2 Basic Feasible Solution by VAM (Optimal)



From \ To		C ₁	C ₂	C ₃	Dummy	Row Penalties					Row Nos. (u _i)			
						Supply	1st	2nd	3rd	4th				
M ₁		8	7	140	6	110	0	250 ¹⁴⁰	6*	2	1	1	u ₁ = 0	
M ₂		300	5	20	4		9	0	320 ²⁰	4	1	5*	–	u ₂ = -2
M ₃			7	240	5	40	5	0	280 ⁴⁰	5	0	0	0	u ₃ = -1
Demand		300	240 ²⁰	260	40	180	110	850						
Column Penalties	1st	2	1	1	0									
	2nd	2*	1	1	–									
	3rd	–	1	1	–									
	4th	–	2*	1	–									
Column Nos. (v _j)		v ₁ = 7	v ₂ = 6	v ₃ = 6	v ₄ = 0									

Row Penalty = 2nd lowest cost figure of a row - Lowest cost figure of that row.

For the **1st Set of Row Penalties** -

(a) For 1st row, 2nd lowest cost = 6 and lowest cost = 0

$$\therefore \text{Penalty} = 6 - 0 = 6$$

(b) For 2nd Row, 2nd lowest cost = 4 and Lowest cost = 0

$$\therefore \text{Penalty} = 4 - 0 = 4$$

(c) For 3rd Row, 2nd lowest cost = 5 and Lowest cost = 0,

$$\therefore \text{Penalty} = 5 - 0 = 5$$

Similarly, **Column Penalty** = 2nd lowest cost figure of a column - Lowest cost figure of that column

For the **1st Set of Column Penalties** -

(a) For 1st column, 2nd lowest cost = 7 and Lowest cost = 5, $\therefore$ Penalty = 7 - 5 = 2

(b) For 2nd column, 2nd lowest cost = 5 and Lowest cost = 4, $\therefore$ Penalty = 5 - 4 = 1

(c) For 3rd column, 2nd lowest cost = 6 and Lowest cost = 5, $\therefore$ Penalty = 6 - 5 = 1

Of all these Row and Column penalties of 1st set, 6 is highest and it corresponds to 1st Row.

Hence allocation should be done at that cell of 1st Row where cost is least. This corresponds to the cell (M₁ - Dummy). So maximum possible unit of 110 is allocated in this cell by maintaining parity of supply and demand.

With this allocation the total demand of 'Dummy' site is exhausted. But the supply of the corresponding Mineral Field (M₁) is not fully exhausted. Remaining supply capacity of M₁ i.e. 250 - 110 = 140 tonnes is shown as balance in the supply cell of M₁. As the demand of 'Dummy' is fulfilled, the entire column for this has been shaded indicating the same. Figures of this column will no longer participate in any of the subsequent calculations of Penalty (for Rows as well as columns)

The same procedure of calculating penalty for Rows and Columns and subsequently allocating maximum possible quantity in the least cost cell corresponding to highest penalty is repeated until all the allocations are made maintaining parity of Supply and Demand.

The solution thus obtained is the **Basic Feasible Solution**. It is given as follows.

Table: Showing Optimum Allocation

Cell	Allocation	Cost of Transportation (Rs.)
M ₁ - C ₃	140 tonnes	140 × 6 = 840
M ₁ - Dummy	110 tonnes	110 × 0 = 0
M ₂ - C ₁	300 tonnes	300 × 5 = 1500
M ₂ - C ₂	20 tonnes	20 × 4 = 80
M ₃ - C ₂	240 tonnes	240 × 5 = 1200

M3 - C3	40 tonnes	$40 \times 5 = 200$
Total	850 tonnes	Rs. 3820

Here, m = No. of rows of the matrix = 3

n = No. of columns of the matrix = 4

$\therefore m + n - 1 = 3 + 4 - 1 = 6$

Also, no. of allocated cells = 6

As, no. of allocated cells = 6 = $m + n - 1$, the solution is a **non degenerate** one.

Now the solution is tested for **OPTIMALITY**.

For this, Row Nos. (u_i) and column nos. (v_j) are calculated by using the equation $C_{ij} = u_i + v_j$ for all the **allocated cells**, where C_{ij} = Cost figure of the cell i - j .

Allocated Cell	C_{ij}	$C_{ij} = u_i + v_j$			
$M_1 - C_3$	$C_{13} = 6$	$C_{13} = u_1 + v_3$	or, $6 = u_1 + v_3$	or, $6 = 0 + v_3$ (Assume $u_1 = 0$) or, $v_3 = 6$	(1)
M_1 - Dummy	$C_{14} = 0$	$C_{14} = u_1 + v_4$	or, $0 = u_1 + v_4$	or, $0 = 0 + v_4$ or, $v_4 = 0$	(2)
$M_2 - C_1$	$C_{21} = 5$	$C_{21} = u_2 + v_1$	or, $5 = u_2 + v_1$	or, $5 = -2 + v_1$ or, $v_1 = 7$	(6)
$M_2 - C_2$	$C_{22} = 4$	$C_{22} = u_2 + v_2$	or, $4 = u_2 + v_2$	or, $4 = u_2 + 6$ or, $u_2 = -2$	(5)
$M_3 - C_2$	$C_{32} = 5$	$C_{32} = u_3 + v_2$	or, $5 = u_3 + v_2$	or, $5 = -1 + v_2$ or, $v_2 = 6$	(4)
$M_3 - C_3$	$C_{33} = 5$	$C_{33} = u_3 + v_3$	or, $5 = u_3 + v_3$	or, $5 = u_3 + 6$ or, $u_3 = -1$	(3)

Hence no. of equations = 6 and no. of unknowns = 7. So to start with a solution, it is assumed $u_1 = 0$.

Thereafter all the other row nos. and column nos. are calculated. The sequence of usage of the above equations is indicated as (1), (2), (3), ... (6).

Next opportunity cost (Δ_{ij}) for all the unallocated cells are calculated using $\Delta_{ij} = C_{ij} - (u_i + v_j)$

Unallocated Cell	C_{ij}	Opportunity Cost [$\Delta_{ij} = C_{ij} - (u_i + v_j)$]
$M_1 - C_1$	$C_{11} = 8$	$\Delta_{11} = C_{11} - (u_1 + v_1) = 8 - (0 + 7) = 1$
$M_1 - C_2$	$C_{12} = 7$	$\Delta_{12} = C_{12} - (u_1 + v_2) = 7 - (0 + 6) = 1$
$M_2 - C_3$	$C_{23} = 9$	$\Delta_{23} = C_{23} - (u_2 + v_3) = 9 - (-2 + 6) = 5$
M_2 - Dummy	$C_{24} = 0$	$\Delta_{24} = C_{24} - (u_2 + v_4) = 0 - (-2 + 0) = 2$
$M_3 - C_1$	$C_{31} = 7$	$\Delta_{31} = C_{31} - (u_3 + v_1) = 7 - (-1 + 7) = 1$
M_3 - Dummy	$C_{34} = 0$	$\Delta_{34} = C_{34} - (u_3 + v_4) = 0 - (-1 + 0) = 1$

As all the opportunity cost values are nonnegative, the solution is optimal.

(i) So the optimal transportation plan is as shown in Table-3 and minimum cost of transportation is Rs. 3820/-

(ii) Quantities to be produced by M_1 , M_2 and M_3 are respectively 250, 320 and 280 tonne of which 110 tonnes worth of stone chips produced by M_1 will remain unused by the construction sites. So this quantity can be sold ex-field.

Illustration 19:

Ladies fashion shop wishes to purchase the following quantity of summer dresses:

Dress size	I	II	III	IV
Quantity	100	200	450	150

Three manufacturers are willing to supply dresses.

The quantities given below are the maximum that they are able to supply of any given combination of orders for dresses:

Manufacturers	A	B	C
Total quantity	150	450	250

The shop expects the profit per dress to vary with the manufacturer as given below:

Size

	I	II	III	IV
A	Rs.2.5	Rs.4.0	Rs.5.0	Rs.2.0
B	Rs.3.0	Rs.3.5	Rs.5.5	Rs.1.5
C	Rs.2.0	Rs.4.5	Rs.4.5	Rs.2.5

Required:

- Use the transportation technique to solve the problem of how the orders should be placed with the manufacturers by the fashion shop is order to maximise profit.
- Explain how you know there is no further improvement possible.

Answer:

Table: 1 Profit Matrix

Dress Size Manufacturer	I	II	III	IV	Supply
A	2.5	4	5	2	150
B	3	3.5	5.5	1.5	450
C	2	4.5	4.5	2.5	250
Demand	100	200	450	150	850
					900

Maximum possible supply capability of manufacturer = 850 units

Total Demand = 900 units

As Supply $\neq$ demand, the problem is an unbalanced one. To make it balanced, a 'Dummy' manufacturer of supply capacity = $900 - 850 = 50$ units. is introduced. The profit figures for it are all zeros.

Also it is a problem of maximisation, to convert it to a problem of minimisation, a Relative Loss matrix is formed by subtracting all the profit figures given in the above matrix as well as those of Dummy from the highest profit (5.5) figure of the given matrix.

Table: 2 Relative Loss Matrix with Basic Feasible Solution

Dress Size Manu- facturer	I	II	III	IV	Supply	Row Penalties		
						1st	2nd	3rd
A	100 3	1.5	0.5	50 3.5	150 ~~50~~	1	1.5	0.5*
B	2.5	2	450 0	4	450 ~~450~~	2*	—	—
C	3.5	200 1	1	50 3	250 ~~50~~	0	2*	0.5
Dummy	5.5	5.5	5.5	50 5.5	50 ~~50~~	0	0	0
Demand	100 ~~100~~	200 ~~200~~	450 ~~450~~	150 ~~150~~	900			
Column Penalties	1st	0.5	0.5	0.5				
	2nd	0.5	0.5	—	0.5			
	3rd	0.5	—	—	0.5			

Here, m = No. of rows of the matrix = 4 and n = No. of columns of the matrix = 4

$$\therefore m + n - 1 = 4 + 4 - 1 = 7$$

Also no. of allocated cells = 6 $\neq$ ($m + n - 1$)

So the solution is a degenerate one. To resolve this, we make use of an artificial quantity 'e' and allocate this quantity at the unallocated cell which is having least cost among all the unallocated cells. It can be mentioned that the quantity 'e' is very small and for all practical purposes its value can be taken as zero.

Least cost unallocated cell is (A-III) where allocation of 'e' has to be made.

Table: 3 Showing Basic Feasible Solution (Optimal)

Dress Size Manufacturer	I	II	III	IV	Supply	Row Nos. (u_i)
A	(100) 3	1.5	(3) 0.5	(50) 3.5	150	$u_1 = 0$
B	2.5	2	(450) 0	4	450	$u_2 = -0.5$
C	3.5	(200) 1	1	(50) 3	250	$u_3 = -0.5$
DUMMY	5.5	5.5	5.5	(50) 5.5	50	$u_4 = 2$
DEMAND	100	200	450	150	900	
Column Nos. (v_j)	$v_1 = 3$	$v_2 = 1.5$	$v_3 = 0.5$	$v_4 = 3.5$		

To test optimality of the Basic Feasible Solution, Row Nos. (u_i) and Column Nos. (v_j) are calculated using the equation $C_{ij} = u_i + v_j$ for the allocated cells, where C_{ij} = Relative Loss figure of the cell $i - j$.

Allocated cell	A-I	A-III	A-IV	B-III	C-II	C-IV	Dummy-IV
C_{ij}	$C_{11} = 3$	$C_{13} = 0.5$	$C_{14} = 3.5$	$C_{23} = 0$	$C_{32} = 1$	$C_{34} = 3$	$C_{44} = 5.5$

$$C_{11} = u_1 + v_1 \quad \text{or, } 3 = 0 + v_1 \text{ [} u_1 = 0, \text{ Assumed] or, } v_1 = 3$$

$$C_{13} = u_1 + v_3 \quad \text{or, } 0.5 = 0 + v_3 \text{ or, } v_3 = 0.5; \quad C_{14} = u_1 + v_4 \text{ or, } 3.5 = 0 + v_4 \quad \text{or, } v_4 = 3.5$$

$$C_{23} = u_2 + v_3 \quad \text{or, } 0 = u_2 + 0.5 \text{ or, } u_2 = -0.5; \quad C_{34} = u_3 + v_4 \quad \text{or, } 3 = u_3 + 3.5 \quad \text{or, } u_3 = -0.5$$

$$C_{32} = u_3 + v_2 \quad \text{or, } 1 = -0.5 + v_2 \text{ or, } v_2 = 1.5; \quad C_{44} = u_4 + v_4 \quad \text{or, } 5.5 = u_4 + 3.5 \quad \text{or, } u_4 = 2$$

Opportunity Loss figures (Δ_{ij}) for all the unallocated cells are calculated using the equation $\Delta_{ij} = C_{ij} - (u_i + v_j)$

Unallocated Cell	Opportunity Loss (Δ_{ij})
A - II	$\Delta_{12} = C_{12} - (u_1 + v_2) = 1.5 - (0 + 1.5) = 0$
B - I	$\Delta_{21} = C_{21} - (u_2 + v_1) = 2.5 - (-0.5 + 3) = 0$
B - II	$\Delta_{22} = C_{22} - (u_2 + v_2) = 2 - (-0.5 + 1.5) = 1$
B - IV	$\Delta_{24} = C_{24} - (u_2 + v_4) = 4 - (-0.5 + 3.5) = 1$
C - I	$\Delta_{31} = C_{31} - (u_3 + v_1) = 3.5 - (-0.5 + 3) = 1$
C - III	$\Delta_{33} = C_{33} - (u_3 + v_3) = 1 - (-0.5 + 0.5) = 1$
Dummy - I	$\Delta_{41} = C_{41} - (u_4 + v_1) = 5.5 - (2 + 3) = 0.5$
Dummy - II	$\Delta_{42} = C_{42} - (u_4 + v_2) = 5.5 - (2 + 1.5) = 2$
Dummy - III	$\Delta_{43} = C_{43} - (u_4 + v_3) = 5.5 - (2 + 1.5) = 3$

As all the opportunity loss values are non negative, the solution is optimal.

Table Showing Optimum allocation of orders quantities

From Manufacturer	Dress Size	Allocated Quantity	Profit/unit (Rs.)	Total (Rs.)
(i)	(ii)	(iii)	(iv)	(v) = (iii) $\times$ (iv)

A	I	100 units	2.5	250
	IV	50 units	2	100
B	III	450 units	5.5	2475
C	II	200 units	4.5	900
	IV	50 units	2.5	125
Dummy	IV	50 units	0	0
Total	-	900 units	-	Rs. 3850

Maximum Profit = Rs. 3850/-

Illustration 20:

The products of three plants F1, F2 and F3 are to be transported to 5 warehouses W1, W2, W3, W4 and W5. The capacities of plants, demand of warehouses and the cost of transportation from one plant to various warehouses are indicated in the following table:

	W1	W2	W3	W4	W5	Plant Capacity
F1	74	56	54	62	68	400
F2	58	64	62	58	54	500
F3	66	70	52	60	60	600
Warehouse Demand	200	280	240	360	320	1500/1400

- Find out a distribution plan of products from plants to the warehouses at a minimum cost. What is the minimum cost?
- Is there any surplus capacity of the plants? If so, in which plant should we associate that surplus capacity?
- Is there any alternate solution for the optimum solution achieved in

Answer:

- From the given data total plant capacity (1500 units) is more than the total demand of warehouses (1400 units). So the problem is unbalanced. To make it balanced, a 'Dummy' warehouse of demand $1500 - 1400 = 100$ units is introduced. Cost figures corresponding to various cells of this 'Dummy' are zeros.

Table: 1 Basic Feasible Solution

Warehouse Plant	Warehouse						Plant Capacity	Raw Penalties					
	W ₁	W ₂	W ₃	W ₄	W ₅	Dummy		1	2	3	4	5	6
F ₁	74	56	54	62	68	0	120	54	2	6	6	6	6
		(280)		(120)			400						
F ₂	58	64	62	58	54	0	400	*	4	4	4	4	-
	(200)				(200)	(100)	500	54					
F ₃	66	70	52	60	60	0	600	52	*	0	0	0	0
			(240)	(240)	(120)		360	8					
Warehouse Demand	200	280	240	360	320	100	1500						
Column Penalties	1	8	8	2	2	6	0						
	2	8	8	2	2	6	-						
	3	8	8*	-	2	6	-						
	4	8*	-	-	2	6	-						
	5	-	-	-	2	6*	-						
	6	-	-	-	2	8*	-						

Here, $m = \text{No. of rows} = 3$

$n = \text{No. of columns} = 6$

$m + n - 1 = 3 + 6 - 1 = 8$

Also no. of allocated cells = 8 = $m + n - 1$.

So the solution is nondegenerate.

Table: 2 Showing Basic Feasible Solution (Non Optimal)

Warehouse Plant	W ₁	W ₂	W ₃	W ₄	W ₅	Dummy	Plant Capacity	Row Nos. (U _j)
F ₁	74	(280)	54	(120)	62	68	0	400
				(-)			(+)	u ₁ = 8
F ₂	58		62		58	54	74	500
	(200)					(200)	(+)	u ₂ = 0 (left)
						(100)	(-)	
F ₃	66	70	(240)	52	(240)	60	120	600
					(+)	(-)		u ₃ = 6
Warehouse Demand	200	280	240	360	320	100	1500	
Column Nos. (V _j)	V ₁ = 58	V ₂ = 48	V ₃ = 46	V ₄ = 54	V ₅ = 54	V ₆ = 0		

Calculation of Opportunity Costs for Basic Feasible Solution

Unallocated Cell	Opportunity Cost [$\Delta_{ij} = C_{ij} - (u_i + v_j)$]
F ₁ - W ₁	$\Delta_{11} = C_{11} - (u_1 + v_1) = 74 - (8 + 58) = 8$
F ₁ - W ₃	$\Delta_{13} = C_{13} - (u_1 + v_3) = 54 - (8 + 46) = 0$
F ₁ - W ₅	$\Delta_{15} = C_{15} - (u_1 + v_5) = 68 - (8 + 54) = 6$
F ₁ - Dummy	$\Delta_{16} = C_{16} - (u_1 + v_6) = 0 - (8 + 0) = -8$
F ₂ - W ₂	$\Delta_{22} = C_{22} - (u_2 + v_2) = 64 - (0 + 48) = 16$
F ₂ - W ₃	$\Delta_{23} = C_{23} - (u_2 + v_3) = 62 - (0 + 46) = 16$
F ₂ - W ₄	$\Delta_{24} = C_{24} - (u_2 + v_4) = 58 - (0 + 54) = 4$
F ₃ - W ₁	$\Delta_{31} = C_{31} - (u_3 + v_1) = 66 - (6 + 58) = 2$
F ₃ - W ₂	$\Delta_{32} = C_{32} - (u_3 + v_2) = 70 - (6 + 48) = 16$
F ₃ - Dummy	$\Delta_{36} = C_{36} - (u_3 + v_6) = 0 - (6 + 0) = -6$

As all the Opportunity Costs are not nonnegative, the solution is non optimal i.e. further improvement is possible.

For this a loop is formed starting from the cell having highest negative value which is cell (F1 - Dummy) having a highest negative opportunity cost value of -8. The starting cell of the loop is marked with a (+) and thereafter alternately the corner cells of the loop are marked (-) and (+). Next the minimum of the allocated quantities of the cells marked (-) is subtracted from the allocated quantities of all the cells marked (-) and added to all the cells marked (+). This leads to an improved solution as shown below.

Table: 3 Showing Improved Solution (Optimal)

Warehouse Plant	W ₁	W ₂	W ₃	W ₄	W ₅	Dummy	Plant Capacity	Row Nos. {U}
F ₁	74 8	280 56	0 54	20 62	68 6	100 0	400	U ₁ = 0 (Let)
F ₂	200 58	16 64	16 62	4 58	300 54	8 0	500	U ₂ = -8
F ₃	2 66	16 70	240 52	340 60	20 60	2 0	600	U ₃ = -2
Warehouse Demand	200	280	240	360	320	100	1500	
Column Nos. {V}	V ₁ = 66	V ₂ = 56	V ₃ = 54	V ₄ = 62	V ₅ = 62	V ₆ = 0		

Opportunity Costs (Dij) for the unallocated cells are calculated same as before and shown in left bottom corner of the cells.

(a) As $D_{ij} \geq 0$, the solution is optimal.

Table -4: Showing Optimal Distribution Plan

From Plant	To Warehouse	Quantity (Units)	Cost/Unit (Rs.)	Total (Rs.)
(1)	(2)	(3)	(4)	(5) = (3) × (4)
F ₁	W ₂	280	56	15680
	W ₄	20	62	1240
	Dummy	100	0	0
F ₂	W ₁	200	58	11600
	W ₅	300	54	16200
F ₃	W ₃	240	52	12480
	W ₄	340	60	20400
	W ₅	20	60	1200
Total		1500	-	Rs. 78800

Minimum Cost of Transportation is Rs. 78800

(b) Plant F1 is having a surplus quantity of 100 units.

(c) Presence of zero opportunity cost (in the cell F1 - W3) indicates that alternative optimum solution is possible for the problem. To get the solution, we form a loop starting from the cell F1 - W3. The new solution is shown below-

Table-5: Showing Alternative Optimum Solution



Warehouse	W ₁	W ₂	W ₃	W ₄	W ₅	Dummy	Plant Capacity
F ₁	74	56	54	62	68	0	400
		(280)	(20)			(100)	
F ₂	58	64	62	58	54	0	500
	(200)				(300)		
F ₃	66	70	52	60	60	0	600
			(220)	(360)	(20)		
Warehouse Demand	200	280	240	360	320	100	1500

Table-6: Showing Alternative Optimum Distribution Plan

From Plant	To Warehouse	Quantity (Units)	Cost/Unit (Rs.)	Total (Rs.)
(1)	(2)	(3)	(4)	(5) = (3) × (4)
F ₁	W ₂	280	56	15680
	W ₃	20	54	1080
	Dummy	100	0	0
F ₂	W ₁	200	58	11600
	W ₅	300	54	16200
F ₃	W ₃	220	52	11440
	W ₄	360	60	21600
	W ₅	20	60	1200
Total		1500	-	Rs. 78800

So the alternative solution is given above.

Illustration 21:

A company has 4 factories F₁, F₂, F₃, & F₄ manufacturing the same product. Production & raw material cost differ from factory to factory and are given in the following table in the first two rows.

The transportation cost from factories to sales departments S₁, S₂, S₃, are also given. The last two columns in the table give the sales price & the total requirement at each sales department.

The production capacity of each factory is given in the last row.

Factories

Sales Dept.

Factories	F ₁	F ₂	F ₃	F ₄	Sales price / unit	Requirement
Sales Dept.						
Production cost/unit	15	18	14	13		
Raw material cost/unit	10	9	12	9		
Transportation Cost/unit S ₁	3	9	5	5	34	80
S ₂	1	7	4	5	32	120
S ₃	5	8	3	6	31	150
Availability	10	150	50	100		

Determine the most profitable production & the distribution schedule & the corresponding profit. The surplus product should be taken to yield zero profit.

Answer:

Initially in this problem there are four sources (factories) and three destinations (sales Depot)

Total Cost/unit = Production cost/unit + Raw material cost/unit + Transportation Cost/unit.

Profit/unit = Selling Price/unit - (Total Cost/unit)

Total Availability = 310 units & Total requirement = 350 units Since Total Availability not equal to total requirement so it is a unbalanced transportation problem.

Since total availability is less than total requirement we have to introduce a dummy factory with adjustment of 40 units to make balance transportation problem.

Table showing the calculation of per unit Profit matrix

	Sales depot 1	Sales depot 2	Sales depot 3	Availability
Factory 1	$34 - (15 + 10 + 3) = 6$	$32 - (15 + 10 + 1) = 6$	1	10
Factory 2	-2	-2	-4	150
Factory 3	3	2	2	50
Factory 4	7	5	3	100
Factory 5 (Dummy)	0	0	0	40
Requirement	80	120	150	350

Table showing the Calculation of per unit cost matrix [Subtracting each element of cost from biggest element here it is '7']

	Sales depot 1	Sales depot 2	Sales depot 3	Availability
Factory 1	1	1	6	10
Factory 2	9	9	11	150
Factory 3	4	5	5	50
Factory 4	0	2	4	100
Factory 5 (Dummy)	7	7	7	40
Requirement	80	120	150	350

Now we can apply VAM to get initial Basic feasible solutions (IBFS)

For optimality solution we will follow two steps (1) Calculation of Row Penalty (u_i) and column penalty (v_j) by trial and error method on the basis of occupied solution (IBFS).

Total no of initial basic feasible solutions = $m+n-1$ but total no of u_i and v_j are $m + n$ so with the help of $m+n-1$ IBFS we can never solve $m+n$ unknowns so any one of $m+n$ solutions can be solved by trial and error method.

Any one of the u_i or v_j will be zero on the basis of maximum number of occupied cell if no of occupied cells are same for more than one rows or one columns we can consider any of them to maintain the condition of $m+n-1$.

Let C_{ij} be the cost for occupied cell. Using occupied cell costs and one of the trial solution we can calculate the other row penalties and column penalties.

Where, $C_{ij} = u_i + v_j$

After getting all u_i and v_j then we calculate the unoccupied cell using the formula given below:

$C_{ij} - (u_i + v_j)$

where, C_{ij} is the cost of unoccupied cell.

Illustration 22:

Departmental store wishes to purchase the following quantities of Sprees:

Types of spreeds	A	B	C	D	E
Quantity	150	100	75	250	200

Tenders are submitted by 4 different manufacturers who undertake to supply not more than the quantities mentioned below (all types of spreeds combined):

Manufacturer	W	X	Y	Z



Total quantity	300	250	150	200

The store estimates that its profit/spree will vary with the manufacturer as shown in the following matrix.

Manufacturers	Spree				
	A	B	C	D	E
W	275	350	425	225	150
X	300	325	450	175	100
Y	250	350	475	200	125
Z	325	275	400	250	175

How should the orders be placed?

Answer:

Profit matrix:

	A	B	C	D	E	F	
W	275	350	425	225	150	0	300
X	300	325	450	175	100	0	250
Y	250	350	475	200	125	0	150
Z	325	275	400	250	175	0	200
	150	100	75	250	200	125	

Loss Matrix:

	200	125	50	250	325	475	300/275/225/25
	25		50	200		25	
150	175	150	25	300	375	475	250/100/0
						100	25/25/125/75/5
	225	125	0	275	350	475	150/75/0
	75	75					125* 100*
	150	200	75	225	300	475	
			200				200/0
							75/50/50/75/75/75*

$m + n - 1$ allocation s are there, optimality test can be performed.

150	100	75	250	200	125
0	25	0	50	0	100
	0		0		0
25	0	25	25	25	0
25	0		25	25	0
25	25		25	25	0
25			25	25	0
			50	50	0

$M + n - 1$ allocation s are there, optimality test can be performed.

	200	125	50	250	325	475	
	25	25	50	50	200	25	0
	175	150	25	300	375	475	0
150		25	25	50	50	100	0
	225	125	0	275	350	475	0
	50	75	75		25	25	0
	150	200	75	225	300	475	-25
	0	100	100	200	0	25	
	175	125	0	250	325	475	

As $\Delta_{ij} \geq 0$, maximum profit is as follows.

Qty Maximum Profit

W $\longrightarrow$ B $25 \times 350 = 8750$

D $50 \times 225 = 11250$

E $200 \times 150 = 30000$

F $25 \times 0 = 0$

X $\longrightarrow$ A $150 \times 300 = 45000$

F $100 \times 0 = 0$

Y $\longrightarrow$ B $75 \times 350 = 26250$

C $75 \times 475 = 35625$

Z $\longrightarrow$ D $200 \times 250 = 50000$

Max. Profit. 900 Rs. 2,06,875

Illustration 23:

The Bombay Transport Company has trucks available at four different sites in the following numbers:

Site A 5 Trucks

Site B 10 Trucks

Site C 7 Trucks

Site D 3 Trucks

Customers - W, X and Y require trucks as shown below.

Customer W 5 Trucks

Customer X 8 Trucks

Customer Y 10 Trucks

Variable Costs of getting trucks to the Customers are given below:

From A to W	Rs. 7, to X	Rs. 3 to Y	Rs. 6
From B to W	Rs. 4, to X	Rs. 6 to Y	Rs. 8
From C to W	Rs. 5, to X	Rs. 8 to Y	Rs. 4
From D to W	Rs. 8 to X	Rs. 4 to Y	Rs. 3

Solve the above transportation problem.

Answer:

	7		3		6		0	5/0	3	<u>3</u> *	-	-	-
	4	5	6		8		0	10/8/3/0	4*	2	<u>2</u> *	2	2
5			3				2	7/0	4	1	<u>1</u>	4	-
	5		8		4		0						
				7									
	8		4		3		0	3/0	3	1	<u>1</u>	<u>1</u>	<u>1</u>
					3								
	<u>5</u>		<u>8</u>		<u>10</u>		<u>2</u>						

0	3	3	0
	0	0	
1	1	1	0
1	1	1	-
1	2	1	
-	2	1	-
-	2	5	-

	W	X	Y	Z	U _i
A	7	3	6	0	-3
B	4	6	8	0	0
C	5	8	4	0	-1
D	8	4	3	0	-2
			3	1	

	W	X	Y	Z	U _i
A	7	3	6	0	-3
B	4	6	8	0	0
C	5	8	4	0	-1
D	8	4	3	0	-2
			3	1	
U _j	4	6	5	0	

As $\Delta_{ij} \geq 0$, the solution is optimum.

Allocation:

Minimum Cost

$$A \rightarrow X \rightarrow 5 \times 3 = 15$$

$$B \rightarrow W \rightarrow 5 \times 4 = 20$$

$$\rightarrow X \rightarrow 3 \times 6 = 18$$

$$\rightarrow Z \rightarrow 2 \times 0 = 0$$

$$C \rightarrow Y \rightarrow 7 \times 4 = 28$$

$$D \rightarrow Y \rightarrow 3 \times 3 = 9$$

$$\mathbf{25 \quad Rs. 90}$$

Illustration 24:

A company has 3 plants located at different places but producing an identical product. The cost of production, distribution cost of each plant to the 3 different warehouses, the sale price at each warehouse and the individual capacities for both the plant and warehouse are given below:

Plants	F1	F2	F3		
Raw material	15	18	14		
Other expenses	10	9	12		
Distribution cost to warehouse				Sales Price in (Rs.)	Warehouse Capacity (No)
W1	3	9	5	34	80
W2	1	7	4	32	110
W3	5	8	3	31	150
Capacity of Plant (No.)	150	100	130		

Establish a suitable table giving net profit/loss for a unit produced at different plants and distributed at different locations.

- Introduce a suitable dummy warehouse / plant so as to match the capacities of plants and warehouses.
- Find distribution pattern so as to maximize profit / minimize loss.
- Interpret zero value of square evaluation of an empty cell and find alternative solutions.

Answer:

Profit matrix

6	-2	3	80
6	-2	2	110
1	-4	2	150
0	0	0	40
150	100	130	380

Loss Matrix:

0	8	3	80/40/0	3/3/5
40	40		110/2	4*
0	8	4	150/20/0	1/1/6*
5	10	4	10/0	0/0/0
20	130			
6	6	6		
40				

40	0	8	3
			1
110	0	8	4
		0	2
	5	10	4
	3	20	130
	6	6	6
	4	40	6
0	8	2	6

		Quantity	Maximum Profit
F1	W1	40 × 6	240
	W2	40 × -2	-80
F2	W1	110 × 6	660
F3	W2	20 × -4	-80
	W3	130 × 2	260
F4 Dummy	W2	40 × 0	0
		380	Rs. 1000

Prof. Asif Pazheri

4.6 Job Evaluation, Job Allocation, Assignment

Questions For Classroom Discussion

Assignment Problem

(Hungarian Method)

Different Methods of Solving Assignment Problem

- 1) Complete Enumeration Method
- 2) Simplex Method
- 3) Transportation Problem
- 4) Hungarian Method

Question 1

Road Construction Project by the Ministry of PWD

The Ministry of Public Works Department (PWD) has undertaken a project to construct four roads. The department has decided to award a maximum of one road to each contractor. The objective is to complete the construction of all roads at the minimum cost within a common timeframe. Four contractors have submitted their tender quotes as detailed below.

	Contractor 1	Contractor 2	Contractor 3	Contractor 4
Road 1	12	30	21	15
Road 2	18	33	9	31
Road 3	44	25	21	21
Road 4	14	30	28	14

As a Cost and Management Accountant student, you can assist the PWD Department in reducing the total cost of constructing all roads by implementing the following strategies:

Question 2

Consider the problem of assigning five jobs to five persons. The assignment costs are given as follows.

	J1	J2	J3	J4	J5
E1	8	4	2	6	1
E2	0	9	5	5	4
E3	3	8	9	2	6
E4	4	3	1	0	3
E5	9	5	8	9	5

Problems of Type 2

Multiple Solutions

Question 3

Given below is the time (days) required when a particular program is assigned to a particular programmer.

	A	B	C	D
P1	12	10	8	9
P2	8	9	11	7
P3	11	14	12	10
P4	9	9	8	9

Question 4

Solve the minimal assignment problem whose effectiveness matrix is

	J1	J2	J3	J4
A	2	3	4	5
B	4	5	6	7
C	7	8	9	8
D	3	5	8	4

- 1) A > J2, B > J3, C > J4, D > J1
- 2) A > J3, B > J2, C > J4, D > J1
- 3) A > J1, B > J2, C > J3, D > J4
- 4) A > J1, B > J3, C > J2, D > J4
- 5) A > J2, B > J1, C > J3, D > J4
- 6) A > J2, B > J3, C > J1, D > J4
- 7) A > J3, B > J1, C > J2, D > J4
- 8) A > J3, B > J2, C > J1, D > J4

Drawing Straight Line Problems of Type 3

Question 5

A project work consists of three major jobs for which three contractors have submitted tenders. The tender amounts quoted in Lakhs of Rupees are given in the matrix below.

	A	B	C
C1	17	25	31
C2	10	25	16
C3	12	14	11

Question 6

Solve the following assignment problem

	J1	J2	J3	J4	J5
A	1	3	2	3	6
B	2	4	3	1	5
C	5	6	3	4	6
D	3	1	4	2	2
E	1	5	6	5	4

Question 7

Solve the following assignment problem for minimizing cost.

	J1	J2	J3	J4
A	32	26	35	38
B	27	24	26	32
C	28	22	25	34
D	10	10	16	16

Maximisation of Assignment Problem

Question 8

Given below is a matrix showing the profit for different jobs done through different machines. Find an assignment program which will maximize the total profit.

	M1	M2	M3	M4
J1	51	53	54	50
J2	47	50	48	50
J3	49	50	60	61
J4	63	64	60	61

Question 9

A college department chairman has the problem of providing instructions for the courses offered by his department at the highest possible level of educational quality. He has arrived at the following relative ratings regarding the ability of each instructor to each of the four courses

	OPM	Costing	Tax	FM
Faculty 1	4	3	2	5
Faculty 2	5	3	2	5
Faculty 3	4	4	3	2
Faculty 4	3	4	5	2

Unbalanced Assignment Problem

Question 10

A company has four machines to do three jobs. Each job can be assigned to one and only one machine. The cost of each job on each machine is given in the following table. What are job assignments, which will minimize the cost?

	J1	J2	J3	J4
A	18	24	28	32
B	8	13	17	19
C	10	15	19	22
	***	***	***	***

Question 11

Solve the maximisation Problem

	A	B	C	D	E
M1	62	78	50	101	82
M2	71	84	61	73	59
M3	87	92	111	71	81
M4	48	64	87	77	80

Prohibited Assignment Problem (Restricted Assignment Problem)

Question 12

In the modification of a plant lay out of a factory four new machine M1, M2, M3, M4 are to be installed in a machine shop. There are five vacant places A, B, C, D, and E available. Because of the limited space

machine M2 cannot be placed at C and M3 cannot be placed at A. The cost of locating places to machines is shown below. Find the optimal assignment schedule?

Which space remains vacant after assignment?

	A	B	C	D	E
M1	9	11	15	10	11
M2	12	9	****	10	9
M3	***	11	14	11	7
M4	14	8	12	7	8

Travelling Salesman Problem

Question 13

A salesman has to visit five cities A,B,C,D,E. The distances between cities are given in the table below. If the salesman starts from the City A and has to come back to City A. Which route should he select, so that total distance travelled by him is minimized?

	A	B	C	D	E
A	*	4	7	3	4
B	4	*	6	3	4
C	7	6	*	7	5
D	3	3	7	*	7
E	4	4	5	7	*

Question 14

Solve the following travelling salesman problem.

	A	B	C	D	E
A	***	10	25	25	10
B	1	***	10	15	2
C	8	9	***	20	10
D	14	10	24	***	15
E	10	8	25	27	***

Question 15

Previous year Question

A project consists of four major jobs. For which four contractors submitted tenders. The tender amounts, in thousand of Rupees, are given below.

	A	B	C	D
A	110	98	75	95
B	85	95	115	65
C	105	135	125	98
D	95	95	75	95

Question 16

Previous Year Question - June 2015 - 16 Marks

A department head has four sub ordinates and four tasks have to be performed. Sub ordinates differ in efficiency and tasks differ in their intrinsic difficulty. Time each man would take to perform each task is given in the effectiveness matrix. How the task would be allotted to each person so as to minimize the total man hours?

	J1	J2	J3	J4
A	8	26	17	11
B	13	28	4	26
C	38	19	18	15
D	19	26	24	10

The questions from the institute material follow this one. After this question, we have completed the six questions available in the institute material. Please refer to the institute material for further details.

Illustration From Study Material

Illustration 25:

Six men are available for different jobs. From past records the time in hours taken by different persons for different jobs are given below.

		Jobs					
Men		1	2	3	4	5	6
	1	2	9	2	7	9	1
	2	6	8	7	6	14	1
	3	4	6	5	3	8	1
	4	4	2	7	3	10	1
	5	5	3	9	5	12	1
	6	9	8	12	13	9	1

Find out an allocation of men to different jobs which will lead to minimum operation time.

Answer:

Job	1	2	3	4	5	6
Man	1	2	3	4	5	6
1	2	9	2	7	9	1
2	6	8	7	6	14	1
3	4	6	5	3	8	1
4	4	2	7	3	10	1
5	5	3	9	5	12	1
6	9	8	12	13	9	1

Row Operation* (Table - 1)

Job	1	2	3	4	5	6
Man	1	2	3	4	5	6
1	1	8	1	6	8	0
2	5	7	6	5	13	0
3	3	5	4	2	7	0
4	3	1	6	2	9	0
5	4	2	8	4	11	0
6	8	7	11	12	8	0

* Matrix is obtained by subtracting min. element of each row of the given Matrix from all the elements of the corresponding row.

Column Operation* (Table - 2)

Job	1	2	3	4	5	6
Man	1	2	3	4	5	6
1	0	7	0	4	1	0
2	4	6	5	3	6	0
3	2	4	3	0	0	0
4	2	0	5	0	2	0
5	3	1	7	2	4	0
6	7	6	10	10	1	0

* Matrix is obtained by subtracting min. element of each column of Table - 1 from all the elements of the corresponding column.

Table - 3

Man \ Job	1	2	3	4	5	6
1	0	7	0	4	1	0
2	4	6	5	3	6	0
3	2	4	3	0	0	0
4	2	0	5	0	2	0
5	3	1	7	2	4	0
6	7	6	10	10	1	0

All the zeros obtained in Table - 2 are covered by minimum no. of horizontal and vertical straight lines and shown above. Here order of the given matrix = 6 and minimum no. of horizontal and vertical lines = 4.

As $4 \neq 6$, the solution is non optimal.

Table - 4

Man \ Job	1	2	3	4	5	6
1	0	7	0	4	1	1
2	3	5	4	2	5	0
3	2	4	3	0	0	1
4	2	0	5	0	2	1
5	2	0	6	1	3	0
6	6	5	9	9	0	0

Above table is obtained by subtracting minimum uncovered element of Table - 3 from all the uncovered elements and by adding the same to all the elements at the junction of the intersecting straight lines. Minimum no. of horizontal and vertical straight lines to cover all the zeros = $5 \neq 6$ (order of the matrix). So the solution is non optimal.

Table - 5

Man \ Job	1	2	3	4	5	6
1	~~0~~	9	0	6	3	3
2	1	5	2	2	5	0
3	0	4	1	0	~~0~~	1
4	0	0	3	0	2	1
5	0	0	4	1	3	~~0~~
6	4	5	7	9	0	~~0~~

Above table is obtained by subtracting minimum uncovered element (2) of Table - 4 from all the uncovered elements and by adding the same to all the elements at the junction of the intersecting straight lines. Here minimum no. of horizontal or vertical straight lines to cover all the zeros = 6 = Order of the Matrix. So the solution is optimal.

Table - 6 Showing Optimum Solution - 1

Man \ Job	1	2	3	4	5	6
1	∞	9	0	6	3	3
2	1	5	2	2	5	0
3	0	4	1	∞	∞	1
4	∞	∞	3	0	2	1
5	∞	0	4	1	3	∞
6	4	5	7	9	0	∞

Table - 7 Showing Optimum Solution - 2

Man \ Job	1	2	3	4	5	6
1	∞	9	0	6	3	3
2	1	5	2	2	5	0
3	∞	4	1	0	∞	1
4	0	∞	3	∞	2	1
5	∞	0	4	1	3	∞
6	4	5	7	9	0	∞

Table - 8 Showing Optimum Solution - 3

Man \ Job	1	2	3	4	5	6
1	∞	9	0	6	3	3
2	1	5	2	2	5	0
3	∞	4	1	0	∞	1
4	∞	0	3	∞	2	1
5	0	∞	4	1	3	∞
6	4	5	7	9	0	∞

So the Optimal Assignments are as follows:

As per Table - 6			As per Table - 7			As per Table - 8		
Man	Job	Time (hrs.)	Man	Job	Time (hrs.)	Man	Job	Time (hrs.)
1	3	2	1	3	2	1	3	2
2	6	1	2	6	1	2	6	1
3	1	4	3	4	3	3	4	3
4	4	3	4	1	4	4	2	3
5	2	3	5	2	3	5	1	5
6	5	9	6	5	9	6	5	9
Total	-	22	Total	-	22	Total	-	22

Minimum total operation time = 22 hrs.

Illustration 26:

A captain of a cricket team has to allot five middle batting positions to five batsmen. The average runs scored by each batsman at these positions are as follows:

Batsmen	Batting Position					
		III	IV	V	VI	VII
	A	40	40	35	25	50
	B	42	30	16	25	27
	C	50	48	40	60	50
	D	20	19	20	18	25
	E	58	60	59	55	53

Make the assignment so that the expected total average runs scored by these batsmen are maximum.

Answer:

This is a problem of Maximisation. To solve it using Assignment technique it has to be converted to a Minimisation problem by forming a Relative Loss Matrix.

Batsman	Batting Position				
	III	IV	V	VI	VII
A	40	40	35	25	50
B	42	30	16	25	27
C	50	48	40	60	50
D	20	19	20	18	25
E	58	60	59	55	53

Relative Loss Matrix*

Batsman	Batting Position				
	III	IV	V	VI	VII
A	20	20	25	35	10
B	18	30	44	35	33
C	10	12	20	0	10
D	40	41	40	42	35
E	2	0	1	5	7

* This matrix is formed by subtracting all the elements of the given matrix from the highest element (60) of it.

Row Operation Matrix

Batsman	Batting Position				
	III	IV	V	VI	VII
A	10	10	15	25	0
B	0	12	26	17	15
C	10	12	20	0	10
D	5	6	5	7	0
E	2	0	1	5	7

Column Operation Matrix

Batting Position

Batting Position Batsman	III	IV	V	VI	VII
A	10	10	14	25	0
B	0	12	25	17	15
C	10	12	19	0	10
D	5	6	4	7	0
E	2	0	0	5	7

Minimum no. of horizontal and vertical straight lines to cover all the zeros = 4 $\neq$ Order of the matrix(5).
So the solution is non optimal.

Improved Matrix

	Batting Position				
Batsman	III	IV	V	VI	VII
A	10	6	10	25	0
B	0	8	21	17	15
C	10	8	15	0	10
D	5	1	0	7	X
E	6	0	X	9	11

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 = Order of the matrix. So the solution is optimal.

Optimal Assignment

Batsman	Batting Position	Average runs scored
A	VII	50
B	III	42
C	VI	60
D	V	20
E	IV	60
	Total =	232

Expected maximum total runs = 232

Illustration 27:

Average time taken by an operator on a specific machine is tabulated below. The management is considering replacing one of the old machines by a new one and the estimated time for operation by each operator on the new machine is also indicated.

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	2	3	2	1	4	5	6
02	4	4	6	3	2	5	1
03	6	10	8	4	7	6	1
04	8	7	6	5	3	9	4

05	7	3	4	5	4	3	12
06	5	5	6	7	8	1	6

- (a) Find out an allocation of operators to the old machines to achieve a minimum operation time.
 (b) Reset the problem with the new machine and find out the allocation of the operators to each machine and comment on whether it is advantageous to replace an old machine to achieve a reduction in operating time only.
 (c) How will the operators be reallocated to the machines after replacement?

Answer:

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	2	3	2	1	4	5	6
02	4	4	6	3	2	5	1
03	6	10	8	4	7	6	1
04	8	7	6	5	3	9	4
05	7	3	4	5	4	3	12
06	5	5	6	7	8	1	6

(a) Matrix after Row Operation

Operator	Machines					
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆
01	2	3	2	1	4	5
02	4	4	6	3	2	5
03	6	10	8	4	7	6
04	8	7	6	5	3	9
05	7	3	4	5	4	3
06	5	5	6	7	8	1

Operator	Machines					
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆
01	1	2	1	0	3	4
02	2	2	4	1	0	3
03	2	6	4	0	3	2
04	5	4	3	2	0	6
05	4	0	1	2	1	0
06	4	4	5	6	7	0

To find out the allocation of the Old Machines to the operators we consider the given matrix without the new machine.

Matrix after Column Operation

Operator	Machines					
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆
01	0	2	0	0	3	4
02	1	2	3	1	0	3
03	1	6	3	0	3	2
04	4	4	2	2	0	6
05	3	0	0	2	1	0
06	3	4	4	6	7	0

Minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 $\neq$ order of the matrix (6). So the solution is non optimal.

Optimal Assignment

Operators	01	→	M3	-	2
	02	→	M1	-	4
	03	→	M4	-	4

Improved matrix

Operator	Machines					
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆
01	0	2	0	1	4	5
02	0	1	2	1	0	3
03	0	5	2	0	3	2
04	3	3	1	2	0	6
05	3	0	0	3	2	1
06	2	3	3	6	7	0

Minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 = Order of the matrix. So the solution is optimal.



04	→	M5	-	3
05	→	M2	-	3
06	→	M6	-	1

17 Hours Minimum Operation Time

(b) & (c)

Operator	Machines						
	M1	M2	M3	M4	M5	M6	New
01	2	3	2	1	4	5	6
02	4	4	6	3	2	5	1
03	6	10	8	4	7	6	1
04	8	7	6	5	3	9	4
05	7	3	4	5	4	3	12
06	5	5	6	7	8	1	6
Dummy	0	0	0	0	0	0	0

With the introduction of a new machine into the system, the problem becomes unbalanced one. To make it balanced, a Dummy operator is introduced and all the elements of the matrix corresponding to it are taken as zero.

(1) Matrix after Row Operation

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	1	2	1	0	3	4	5
02	3	3	5	2	1	4	0
03	5	9	7	3	6	5	0
04	5	4	3	2	0	6	1
05	~~4~~	~~0~~	~~1~~	~~2~~	~~1~~	~~0~~	~~9~~
06	4	4	5	6	7	0	5
Dummy	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~

As all the columns contain zeros, the matrix after column operation will remain same. So the operation need not be done.

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 ≠ order of the matrix (7). So the solution is non optimal.

(2) Improved Matrix

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	~~0~~	~~1~~	~~0~~	~~0~~	~~3~~	~~4~~	~~5~~
02	2	2	4	2	1	4	0
03	4	8	6	3	6	5	0
04	4	3	2	2	0	6	1
05	4	0	1	3	2	1	10
06	3	3	4	6	7	0	5
Dummy	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~	~~1~~	~~1~~

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 ≠ order of the matrix (7). So the solution is non optimal.

(3) Improved Matrix

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	0	2	0	0	4	5	6
02	1	2	3	1	1	4	0
03	3	8	5	2	6	5	0
04	3	3	1	1	0	6	1
05	3	0	0	2	2	1	10
06	2	3	3	5	7	0	5
Dummy	0	1	0	1	2	2	2

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 ≠ order of the matrix(7). So the solution is non optimal.

(4) Improved Matrix Showing Optimal Solution (i)

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	0	2	✗	✗	5	6	7
02	✗	1	2	0	1	4	✗
03	2	7	4	1	6	5	0
04	2	2	✗	✗	0	6	1
05	3	0	✗	2	3	2	11
06	1	2	2	4	7	0	5
Dummy	✗	1	0	1	3	3	3

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 7 = order of the matrix. So the solution optimal.

Improved Matrix Showing Optimal Solution (ii)

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	✗	2	0	✗	5	6	7
02	✗	1	2	0	1	4	✗
03	2	7	✗	1	6	5	0
04	2	2	✗	✗	0	6	1
05	3	0	0	2	3	2	11
06	1	2	2	4	7	0	5
Dummy	0	1	✗	1	3	3	3

Improved Matrix Showing Optimal Solution (iii)

Operator	Machines						
	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	New
01	✗	2	✗	0	5	6	7
02	0	1	2	✗	1	4	✗
03	2	7	4	1	6	5	0
04	2	2	✗	✗	0	6	1
05	3	0	✗	2	3	2	11
06	1	2	2	4	7	0	5
Dummy	✗	1	0	1	3	3	3

Table Showing Multiple Optimum Allocations

Solution (i)			Solution (ii)			Solution (iii)		
Operators	M/C	Time (Hrs.)	Operators	M/C	Time (Hrs.)	Operators	M/C	Time (Hrs.)
01	M1	2	01	M3	5	01	M4	1
02	M4	3	02	M4	1	02	M1	4
03	New	1	03	New	6	03	New	1
04	M5	3	04	M5	0	04	M5	3
05	M2	3	05	M2	3	05	M2	3
06	M6	1	06	M6	7	06	M6	1
Dummy	M3	0	Dummy	M1	3	Dummy	M3	0
Total	-	13*	Total	-	13*	Total	-	13*

* Minimum Operation Time

From above it can be said that replacement of an old machine with the new one will result in a reduction in Total Operating Time by $17-13 = 4$ Hours. So replacement decision is advantageous.

As per solutions (i) & (iii) above, Machine M3 should be replaced by a New Machine and as per Solution (iii), M₁ should be replaced by a New one.

Illustration 28:

Six salesmen are to be allocated to six sales regions so that the cost of allocation of the job will be minimum.

Each salesman is capable of doing the job at different cost in each region. The cost matrix is given below:

Salesmen	Region						
		I	II	III	IV	V	VI
	A	15	35	0	25	10	45
	B	40	5	45	20	15	20
	C	25	60	10	65	25	10
	D	25	20	35	10	25	60
	E	30	70	40	5	40	50
	F	10	25	30	40	50	15

(Figures are in Rupees)

- Find the allocation to give minimum cost. What is the minimum cost?
- Now suppose the above table gives earning of each salesman at each region. How can you find an allocation so that the earning will be maximum? Determine the solution with optimum earning.
- There are restrictions for commercial reasons that A cannot be posted to region V and E cannot be posted to region II. Write down the cost matrix suitably after imposing the restrictions.

Answer:

Matrix after Row Operation

	Region					
Salesman	I	II	III	IV	V	VI
A	15	35	0	25	10	45
B	40	5	45	20	15	20
C	25	60	10	65	25	10

	Region					
Salesman	I	II	III	IV	V	VI
A	15	35	0	25	10	45
B	35	0	40	15	10	15
C	15	50	0	55	15	0

D	25	20	35	10	25	60
E	30	70	40	5	40	50
F	10	25	30	40	50	15

Matrix after Column Operation

Salesman	Region					
	I	II	III	IV	V	VI
A	15	35	0	25	10	45
B	35	0	40	15	0	15
C	15	50	0	55	5	0
D	15	10	25	0	5	50
E	25	65	35	0	25	45
F	0	15	20	30	30	5

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 $\neq$ Order of the matrix (6).
So the solution is non optimal.

D	15	10	25	0	15	50
E	25	65	35	0	35	45
F	0	15	20	30	40	5

Improved Matrix (Optimal)

Salesman	Region					
	I	II	III	IV	V	VI
A	20	35	0	30	10	45
B	40	0	40	20	10	15
C	20	50	10	60	5	0
D	15	5	20	10	0	45
E	25	60	30	0	20	40
F	0	10	15	30	30	10

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 = Order of the matrix.
So the solution is optimal.

Table showing optimal allocation

Salesman	Region	Cost (Rs.)	
A	III	0	
B	II	5	
C	VI	10	
D	V	25	
E	IV	5	
F	I	10	
Total		Rs. 55	Minimum Cost

(b) The given problem is a problem of Maximisation. To convert it to a problem of Minimisation, a Relative Loss Matrix is formed by subtracting all the elements of the given matrix from the highest element (70).

Relative Loss Matrix Matrix after Row Operation

Salesman	Region					
	I	II	III	IV	V	VI
A	55	35	70	45	60	25
B	30	65	25	50	55	50
C	45	10	60	5	45	60
D	45	50	35	60	45	10
E	40	0	30	65	30	20
F	60	45	40	30	20	55

Salesman	Region					
	I	II	III	IV	V	VI
A	30	10	45	20	35	0
B	5	40	0	25	30	25
C	40	5	55	0	40	55
D	35	40	25	50	35	0
E	40	0	30	65	30	20
F	40	25	20	10	0	35

Matrix after Column Operation

Salesman	Region					
	I	II	III	IV	V	VI
A	25	10	45	20	35	0
B	0	40	0	25	30	25
C	35	5	55	0	40	55
D	30	40	25	50	35	0
E	35	0	30	65	30	20
F	35	25	20	10	0	35

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 $\neq$ Order of the matrix (6).
So the solution is non optimal.

Improved Matrix (Optimal)

Salesman	Region					
	I	II	III	IV	V	VI
A	0	10	20	20	30	~~0~~
B	~~0~~	65	0	50	50	50
C	10	5	30	0	35	55
D	5	40	~~0~~	50	30	0
E	10	0	5	65	25	20
F	15	30	~~0~~	15	0	40

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 6 = Order of the matrix. So the solution is optimal.

(c) The cost matrix after imposing the given restriction is

Region

		I	II	III	IV	V	VI
Sales man	A	15	35	0	25	a	45
	B	40	5	45	20	15	10
	C	25	60	10	65	25	10
	D	25	20	35	10	25	60
	E	30	a	40	5	40	50
	F	10	25	30	40	50	15

Cost (figures are in Rs.)

(Whenever such restrictions are imposed, we have to consider the corresponding element of the given matrix as infinitely large i.e. a)

Illustration 29:

Four jobs can be processed on four different machines, with one job on one machine. Resulting profits vary with assignments. They are given below:

		Machines			
Jobs		A	B	C	D
	I	42	35	28	21
	II	30	25	20	15
	III	30	25	20	15
	IV	24	20	16	12

Find the optimum assignment of jobs to machines and the corresponding profit.

Answer:

Relative Loss Matrix

M/cs \ Jobs	A	B	C	D	As this is a problem of Maximization, the same is converted to one of Minimization by forming a Relative Loss Matrix where all the elements of the given matrix are subtracted from the highest element of the matrix (which is 42 in this case)
I	0	7	14	21	
II	12	17	22	27	
III	12	17	22	27	
IV	18	22	26	30	

Matrix after Row Operation

M/cs \ Jobs	A	B	C	D
I	0	7	14	21
II	0	5	10	15
III	0	5	10	15
IV	0	4	8	12

Matrix after Column Operation

M/cs \ Jobs	A	B	C	D
I	0	3	6	9
II	0	1	2	3
III	0	1	2	3
IV	0	0	0	0

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 2 $\neq$ Order of the matrix (4)

So the solution is non optimal.

Improved Matrix (Non Optimal)

M/cs \ Jobs	A	B	C	D
I	0	2	5	8
II	0	0	1	2
III	0	0	1	2
IV	1	0	0	0

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 3 $\neq$ Order of the matrix (4)

So the solution is non optimal.

Further Improved Matrix [Optimal Solution (i)]

M/cs \ Jobs	A	B	C	D
I	0	2	4	7
II	×	0	×	1
III	×	×	0	1
IV	1	1	×	0

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 4 = Order of the matrix.

So the solution is optimal.



Further Improved Matrix (Optimal Solution-ii)

Assignment as per Soution (i)			Assignment as per Soution (ii)		
Jobs	M/cs	Profit (₹)	Jobs	M/cs	Profit (₹)
I	A	42	I	A	42
II	B	25	II	C	20
III	C	20	III	B	25
IV	D	12	IV	D	12
Total	–	₹ 99	Total	–	₹ 99

M/cs \ Jobs	A	B	C	D
I	0	2	4	7
II	∞	∞	0	1
III	∞	0	∞	1
IV	2	1	∞	0

Maximum Profit Rs. 99

Illustration 30:

A salesman has to visit five cities A, B, C, D and E. The inter-city distances are tabulated below. Note the distance between two cities need not be same both ways.

From / To	A	B	C	D	E
A	-	12	24	25	15
B	6	--	16	18	7
C	10	11	--	18	12
D	14	17	22	--	16
E	12	13	23	25	--

Note further that the distances are in km.

Required:

If the salesman starts from city A and has to come back to city A, which route would you advise him to take so that total distance traveled by him is minimized?

Answer:

To \ From	A	B	C	D	E
A	-	12	24	25	15
B	6	-	16	18	7
C	10	11	-	18	12
D	14	17	22	-	16
E	12	13	23	25	-

Row Operation*

(Table - 1)

To \ From	A	B	C	D	E
A	-	0	12	13	3
B	0	-	10	12	1
C	0	1	-	8	2
D	0	3	8	-	2
E	0	1	11	13	-

* This matrix is obtained by subtracting minimum element of each row of the given matrix from all the elements of the corresponding row.

Column Operation*

(Table - 2)

To From	A	B	C	D	E
A	+	0	4	5	2
B	×	—	2	4	0
C	×	1	—	0	1
D	×	3	0	—	1
E	0	1	3	5	—

* This matrix is obtained by subtracting minimum element of each column of Table-1 from all the elements of the corresponding column.

Here minimum no. of horizontal and vertical straight lines to cover all the zeros = 5 = Order of the matrix.

So the solution is optimal.

Now the solution obtained from the above table shows the travel route of the salesman as A to B, B to E, E to A which means the person is not visiting C and D at all while travelling back to A.

But this is not allowed as per the question.

So the matrix of Table-2 is examined for some of the next best solution which is depicted below.

To From	A	B	C	D	E
A	—	0	4	5	2
B	×	—	2	4	0
C	0	1	—	×	1
D	×	3	0	—	1
E	×	1	3	5	—

Here the assignments have been started by encircling only zero present in the first row which means initial travel route A to B.

Then the only zero present in the last column is encircled which shows subsequent route B to E. Next the only zero of the last row is not encircled because in that case the route would have been E to A which is restricted as per the given condition. So that element of this row is considered which satisfies the restriction. It is 5 indicating the route as E to D. Next the only zero of 3rd column is encircled which means the route as D to C. Finally the only zero row present in the 3rd row is encircled which shows the route as C to A.

Hence the complete route of the Salesman is : $A \rightarrow B \rightarrow E \rightarrow D \rightarrow C \rightarrow A$

Total distance travelled = $12 + 7 + 25 + 22 + 10 = 76$ Kms.

This is the optimum distance.

4.7 Scheduling

Questions For Classroom Discussion

Please insert Institute Material Illustration 31 (Scheduling Question, Job, Processing Time, Weight)

Queueing theory

Queuing Theory

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

- ☐ Probability that service is busy (Not idle) (Percentage of Utilization)

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

- ☐ Probability that service is idle (Not Busy) (Percentage of Non Utilization)

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

- ☐ Probability that 'n' unit in the system

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

- ☐ 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 in the queue is at least 'n'

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

Question 1

A repair shop attended by a single machine has an average of four customers an hour who bring small appliances. The mechanic inspects them for defects and often can fix them right away or otherwise render a diagnosis. This takes him six minutes, on the average. Arrivals are Poisson and service time has exponential distribution. You are required to

- Q.1 Find the probability that shop is empty
- Q.2 Find the probability of at least one customer in the shop
- Q.3 What is the average number of customers in the system
- Q.4 Find the average time spent, including service.

Question 2

In a railway marshalling yard, goods train arrive at a rate of 30 train per day. Assuming that the inter arrival time follows an exponential distribution and the service time distribution is also exponential with an average of 36 minutes. Calculate the following

- Q.1 Average length of non empty Queue
- Q.2 The probability that the Queue size exceeds 10

Question 3

Customers arrive at a booking office window, being manned by a single individual at the rate of 25 per hour. Time required to serve a customer has exponential distribution with a mean of 120 seconds. Find the average waiting time of customers

Question 4

A TV repairman finds that the time spent on his jobs has an exponential distribution with mean 30 minutes. If the repairs set in the order in which they came in, and if the arrival of sets is approximately Poisson with an average rate of 10 per 8 hour day.

- Q.1 What is repairman's expected idle time each day ?
- Q.2 How many jobs are on an average, ahead of the set just brought in ?

Question 5 Previous Year Question- Home Work

The counter of a ration shop experiences the arrival of 25 customers during peak working hours. Service team will have Poisson distribution. Experiences suggests that means service team should have reached about 2 minutes per customer.

Determine each of the following

- 1) system utilization
- 2) Percentage of the time server will be idle
- 3) Expected number of customers waiting to be served
- 4) Average time customers will spend in the system

Question 6

Previous Year Question- Home Work

A taxi operator is planning to open a computerised ticket counter in the center of the city, staffed by one ticket agent. It is estimated that requests for ticket and information will average 18 per hour and request will have a Poisson distribution.

Server time is estimated to exponentially distributed. Previous Experience with similar Computerised operations suggests that mean service time should average about 2.5 minutes per request.

Determine each of the following

- 1) System Utilisation
- 2) Percentage of time the server (agent) will be idle
- 3) The expected number of customers waiting to be served
- 4) The average time customers will spend in the system.

Illustration From Study Material

Illustration 31:

The processing times (t_j) in hrs for the five jobs of a single machine scheduling is given. Find the optimal sequence which will minimize the mean flow time and find the mean flow time.

Determine the sequence which will minimize the weighted mean flow time and also find the mean flow time

Job (j)	1	2	3	4	5
Processing time (t_j) hrs	30	8	10	28	16
Weight (W_j)	1	2	1	2	3

Answer:

(a) First arrange the jobs as per the shortest processing time (SPT) sequence.

Job (j)	2	3	5	4	1
Processing time (t_j) hrs	8	10	16	28	30

Therefore, the job sequence that minimizes the mean flow time is 2-3-5-4-1.

Computation of minimum flow time (F_{min})

The flow time is the amount of time the job 'j' spends in the system. It is a measure which indicates the waiting of jobs in the system. It is the difference between the completion time (C_j) and ready time (R_j) for job j.

$$F_j = C_j - R_j$$

Job (j)	2	3	5	4	1
Processing time (t_j) hrs	8	10	16	28	30
Completion time (C_j)	8	18	34	62	92

Since the ready time (R_j) = 0 for all j, the flow time F_j is equal to C_j for all j.

$$\text{Mean flow time} = (\bar{F}) = \frac{1}{n} \sum_{j=1}^n F_j = \frac{1}{5} [8 + 18 + 34 + 62 + 92] = \frac{1}{5} [214] = 42.8 \text{ hours}$$

(b) The weights are given as follows:

Job (j)	1	2	3	4	5
Processing time (t_j) hrs	30	8	10	28	16
Weight (W_j)	1	2	1	2	3

$$\text{The weighted processing time} = \frac{\text{Processing time } (t_j)}{\text{Weight } (W_j)}$$

The weighted processing time is represented as

Job (j)	1	2	3	4	5
Processing time (t_j) hrs	30	8	10	28	16
Weight (W_j)	1	2	1	2	3
Weighted Processing time (t_j / W_j)	30	4	10	14	5.31

Thus, arranging the jobs in the increasing order of t_j / W_j (weighted shortest processing time WSPT) we have

Job (j)	2	5	3	4	1
Weighted Processing time (t_j / W_j)	4	5.31	10	14	30

optimal sequence that minimizes the weighted mean flow time is 2-5-3-4-1.

$$\text{Weighted Mean flow time } (\bar{F}_w) : \bar{F}_w = \frac{\sum_{j=1}^n W_j F_j}{\sum_{j=1}^n W_j}$$

Job (j)	2	5	3	4	1
Processing time (t _j) hrs	8	16	10	28	30
F _j = (C _j - R _j)	8	24	34	62	92
W _j	2	3	1	2	1
F _j × W _j	16	72	34	124	92

The weighted mean flow time is computed as follows for optimal sequence.

Weighted mean flow time $\bar{F}_w$ is computed as

$$\bar{F}_w = \frac{(16 + 72 + 34 + 124 + 92)}{(2 + 3 + 1 + 2 + 1)} = 37.55 \text{ hrs.}$$

Illustration 32:

Customers arrive at a bakery at an average rate of 16 per hour on weekday mornings. The arrival can be described by a Poisson distribution with a mean of 16. Each clerk can serve a customer in an average of three minutes; This time can be described by an exponential distribution with a mean of 3.0 minutes.

- What are the arrival and service rates?
- Compute the average number of customers being served at any time.
- Suppose it has been determined that the average number of customers waiting in line is 3.2. compute the average number of customers in the system (i.e., waiting in line or being served), the average time customers wait in line, and the average time in the system.
- Determine the system utilization for $M = 1, 2$, and 3 servers.

Answer:

- The arrival rate is given in the problem: $\lambda = 16$ customers per hour. Change the service time to a comparable hourly rate by first restating the time in hours and then taking its reciprocal. Thus, (3 minutes per customer) / (60 minutes per hour) = $1/20 = 1/\mu$. Its reciprocal is $\mu = 20$ customers per hour = Service Rate.
- Average no. of customers being served at any time.
 $r = \lambda / \mu = 16 / 20 = 0.80$ customer.

Formulas for basic single-server model

Performance Measure	Equation
Average number in line/queue	$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$
Probability of zero units in the system	$P_0 = 1 - \left(\frac{\lambda}{\mu}\right)$
Probability of n units in the system	$P_n = P_0 \left(\frac{\lambda}{\mu}\right)^n$
Probability of less than n units in the system	$P_{<n} = 1 - \left(\frac{\lambda}{\mu}\right)^n$

- Given: $L_q = 3.2$ customers
 $L_s = L_q + r = 3.2 + 0.80 = 4.0$ customers
 Average time customers wait in line
 $= W_q + \frac{L_q}{\lambda} = \frac{3.2}{16} = 0.20$ hour, or $0.20 \text{ hour} \times 60 \text{ minutes/hour} = 12 \text{ minutes}$
 $W_s = \text{Average time customers wait in system} = W_q + \frac{1}{\mu}$
 Waiting time in line plus service
 $0.20 + \frac{1}{20} \text{ hour, or } 15 \text{ minutes}$



d. System utilization is $\rho = \frac{\lambda}{M \times \mu}$

$$\text{For } M = 1, \rho = \frac{16}{1(20)} = 0.80$$

$$\text{For } M = 2, \rho = \frac{16}{2(20)} = 0.40$$

$$\text{For } M = 3, \rho = \frac{16}{3(20)} = 0.27$$

Note that as the system capacity is measured by $M\mu$ increases, the system utilization for a given arrival rate decreases.

Illustration 33:

An airline is planning to open a satellite ticket desk in a new shopping plaza, staffed by one ticket agent. It is estimated that requests for tickets and information will average 15 per hour, and requests will have a Poisson distribution. Service time is assumed to be exponentially distributed. Previous experience with similar satellite operations suggests that mean service time should average about three minutes per request.

Determine each of the following:

- System utilization.
- Percentage of time the server (agent) will be idle.
- The expected number of customers waiting to be served.
- The average time customers will spend in the system.

The probability of zero customers in the system and the probability of four customers in the system.

Answer:

Arrival Rate = $\lambda = 15$ customers per hour

Service Rate = $\mu = \frac{1}{\text{Service Time}} = \frac{1 \text{ customer}}{3 \text{ minutes}} \times 60 \text{ minutes per hour} = 20 \text{ customers per hour}$

a. System Utilisation = $\rho = \frac{\lambda}{M\mu} = \frac{15}{1(20)} = 0.75$

b. Percentage of time the server will be idle = $1 - \rho = 1 - 0.75 = 0.25$, or 25 percent

c. Expected no. of customers waiting to be served = $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{225}{20(20 - 15)} = \frac{225}{(25 \times 5)} = \frac{225}{100} = 2.25 \text{ customers}$

d. Average time customers will spend in the system = $W_s = \frac{L_q}{\lambda} + \frac{1}{\mu} = \frac{2.25}{15} + \frac{1}{20} = 0.20 \text{ hours, or 12 minutes}$

e. Probability of zero customer in the system = $P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{15}{20} = 0.25$ and

Probability of 4 customers in the system $P_4 = P_0 \left(\frac{\lambda}{\mu}\right)^4 = 0.25 \left(\frac{15}{20}\right)^4 = 0.079$

Illustration 34:

Wanda's Car Wash & dry is an automatic, five-minute operation with a single bay. On a typical Saturday morning, cars arrive at a mean rate of eight per hour, with arrivals tending to follow a Poisson distribution. Find

- The average number of cars in line.
- The average time cars spend in line and service.

Answer:

Arrive Rate = $\lambda = 8$ cars per hour

Service Rate = $\mu = 1$ per 5 minutes, or 12 per hour

$$\text{Av. no. of cars waiting in line} = L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)} = \frac{8^2}{2(12)(12-8)} = 0.667 \text{ car}$$

$$\text{Av. time cars spend in line and service} = W_s = \frac{L_q}{\lambda} + \frac{1}{\mu} = \frac{0.667}{8} + \frac{1}{12} = 0.167 \text{ hours, or 10 minutes}$$

Illustration 35:

A departmental store has one cashier. During the rush hours, customers arrive at a rate of 20 per hour. The average number of customers that can be handled by the cashier is 24 per hour. Assume the conditions for use of the single - channel queuing model. Find out average time a customer spends in the system.

Answer:

The usual notations are given:

Arrival Rate = $\lambda = 20$ customers / hour and service rate = $\mu = 24$ customers / hour

$$\text{Average no. of customers in the system} = L_q = \frac{\lambda}{\mu(\mu-\lambda)} = \frac{20}{(24-20)} = \frac{20}{5} = 5 \text{ customers}$$

$$\text{Average time a customer spends in the system} = W_s = \frac{L_s}{\lambda} = \frac{5}{20} = \frac{1}{4} = 0.25 \text{ hour} = 15 \text{ mins}$$

Illustration 36:

As a tool service centre the arrival rate is two per hour and the service potential is three per hour. Simple queue conditions exist.

The hourly wage paid to the attendant at the service centre is Rs.1.50 per hour and the hourly cost of a machinist away from his work is Rs. 4.

Calculate:

- The average number of machinists being served or waiting to be served at any given time.
- The average time a machinist spends waiting for service.
- The total cost of operating the system for an eight - hour day.
- The cost of the system if there were two attendants working together as a team, each paid Rs. 1.50 per hour and each able to service on average 2 per hour.

Answer:

Arrival rate = $\lambda = 2$ per hour

Service rate = $\mu = 3$ per hour

- (i) Average number of machinists being served or waiting to be served at any given time:

$$L_s = \frac{\lambda}{\mu(\mu-\lambda)} = \frac{2}{(3-2)} = 2$$

- (ii) Average Time a machinist spends waiting for the services:

$$W_q = \frac{\lambda}{\mu} \times \frac{1}{(\mu-\lambda)} = \frac{2}{3} \times \frac{1}{(3-2)} = 0.667 \text{ hours}$$

It means a machinist spends 40 minutes (ie., 60×0.667) in the queue.

- (iii) Average time in the system

$$W_s = \frac{1}{(\mu-\lambda)} = \frac{1}{(3-2)} = 1 \text{ hour}$$

Average number of machinists in the system = 2 [As per (i) above]

Cost of two machinists being away from work = Rs. 4 × 2 = Rs.8.00 per hour

Attendant cost = $\frac{1.50 \text{ per hour}}{9.50 \text{ per hour}}$

Cost of 8- hour day = 8 hrs × Rs.9.50 = Rs.76.00

(iv) It is assumed that there is still a single service point, but the average service rate with 2 attendants now is 4 per hour

∴ Now $\lambda = 2$ per hour

$\mu = 4$ per hour

∴ Average number of machinists in the system = $L_s = \frac{\lambda}{\mu - \lambda} = \frac{2}{(4-2)} = 1$

Average time spent by a machinist in the system = $W_s = \frac{1}{(\mu - \lambda)} = \frac{1}{(4-2)} = 12 \text{ hour}$

Machinists cost = 1/2 hr × Rs.4 =	Rs. 2.00
Attendant cost (@ 1.50 per attendant × 2 attendants)	Rs. 3.00
Total Cost	Rs. 5.00

Cost per 8 - hour day = Rs.5 × 8 hrs. = Rs.40.00

Illustration 37:

Workers come to tool store room to enquire about special tools (required by them) for accomplishing a particular project assigned to them. The average time between two arrivals is 60 seconds and the arrivals are assumed to be in Poisson distribution. The average service time (of the tool room attendant) is 40 seconds.

Determine:

- average queue length,
- average length of non-empty queues,
- average number of workers in system including the worker being attended
- mean waiting time of an arrival,
- average waiting time of an arrival who waits.

Answer:

Here, Arrival Rate = $\lambda = \frac{60}{60}$ per second = 1 per minute

Service Rate = $\mu = \frac{60}{40}$ per second = 1.5 per minute

(i) Average queue length:

$$L_q = \frac{\lambda}{\mu} \times \frac{\lambda}{(\mu - \lambda)} = \frac{1}{1.5} \times \frac{1}{(1.5 - 1)} = \frac{1}{0.75} = \frac{4}{3} \text{ workers}$$

(ii) Average length of non-empty queues:

$$L_n = \frac{\mu}{(\mu - \lambda)} = \frac{1}{(1.5 - 1)} = 3 \text{ workers}$$

(iii) Average number of workers in the system:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{1}{(1.5 - 1)} = 2 \text{ workers}$$

(iv) Mean waiting time of an arrival

$$W_q = \frac{\lambda}{\mu} \times \frac{\lambda}{(\mu - \lambda)} = \frac{1}{1.5} \times \frac{1}{(1.5 - 1)} = \frac{3}{4} \text{ minutes}$$

(v) Average waiting time of an arrival who waits

$$W_n = \frac{1}{\mu - \lambda} = \frac{1}{(1.5 - 1)} = 2 \text{ minutes}$$

4.8 Simulation and Line Balancing

Questions For Classroom Discussion

Student Hour Required -6

Monte Carlo Simulation

Question 1

A tourist car operator finds that during the past 100 days the demand for the car had been varied as shown below.

Trips Per Day	0	1	2	3	4	5
Number of Days	8	12	15	30	20	15

Using Random numbers, Simulate the demand for a 10 day period

Use Random Numbers 09, 54, 42, 01, 80, 06, 26, 57, 79, 52

Question 2

A confectioner sells confectionery items. Past data of demand per week in hundred kilograms with frequency is given below:

Demand/ Week	0	5	10	15	20	25
Frequency	2	11	8	21	5	3

Using the following sequence of random numbers, generate the demand for the next 10 weeks.

Also find out the average demand per week

The random Numbers are 35, 52, 13, 90, 23, 73, 34, 57, 35, 83, 94, 56, 67, 66, 60.

Question 3

A trader buys a commodity at Rs. 40 per kg and sells at Rs. 60 per Kg. If any of the commodities remain at the end of the day, it has no saleable value. The loss through unsatisfied demand is Rs. 16 per Kg. Records of the past 250 trading days shows the following.

Supply		Demand	
Quantity Supplied	No of Days of Supply	Quantity Demanded	No of Days of Supply
10	20	10	25
20	25	20	55
30	95	30	100
40	75	40	50
50	35	50	20

- Find net profit in 6 days
- Given the following random numbers 31, 18, 63, 84, 15, 79, 07, 32, 43, 75, 81, 27. Use random numbers alternatively. I.e. First pair 31 to simulate supply, second pair 18 to simulate demand and so on.

Question 4

(Home Work)

A retailer deals in a perishable commodity. The daily demand and supply are variables. The data for the past 500 days show the following demand and supply:

Availability (Supply)		Demand	
Availability (kg)	Supply (No of Days)	Demand (Kg)	Demand (No of Days)
10	40	10	50
20	50	20	110

30	190	30	200
40	150	40	100
50	70	50	40

- The retailer buys the commodity at Rs. 20 per kg. and sells at Rs. 30 per kg. Any commodity remains at the end of the day, has no sales value. Moreover, the loss on unsatisfied demand is Rs. 8 per Kg.
- Given the following pair of random numbers, simulate 6 days sales, demand and profit: (31, 18) (63, 84) (15, 79) (07, 32) (43, 75) (81, 27). The first random number in the pair is that of supply and the second random number is for demand.

After this question, students can attempt Illustrations 40 and 44 as a homework assignment. Hints for solving these illustrations are provided in the upcoming videos.

Question 5

At a service station a study was made over a period of 25 days to determine both the number of automobiles being brought in for service and the number of automobiles serviced. The results are given below.

Number of Auto Mobiles arriving and Servicing	Frequency of Arrival	Frequency of Daily Serviced
0	2	3
1	4	2
2	10	12
3	5	3
4	3	4
5	1	1

- Simulate the arrival and service pattern for a ten-day period and estimate the mean number of automobiles that remain in service for more than a day.
- Use random numbers 09, 54, 42, 01, 80, 06, 06, 26, 67, 79, 49, 16, 36, 76, 68, 91, 97, 85, 56, 84. Use first 10 days for arrival and next 10 days for serviced.

After this question, students can attempt Illustrations 41 as a homework assignment. Hints for solving this illustration are provided in the upcoming videos.

Question 6

An international tourist company deals with numerous personal calls each day and prides itself on its level of service.

The time to deal with each caller depends on the client's requirements which ranges from, say, a request for a brochure to booking around the world cruise.

If a client has to wait for more than 10 minutes for attention. It is company's policy for the manager to see him personally and give him a holiday voucher worth Rs. 15.

The company's observations have shown that the time taken to deal with the clients and arrival pattern of their calls follow the following distribution pattern.

Time to Deal With Clients	Minutes	2	4	6	10	14	20	30
	Probability	0.05	0.10	0.15	0.30	0.25	0.10	0.05
Time Between Arrival	Minutes	1	8	15	25			
	Probability	0.20	0.40	0.30	0.10			

Required:

- Q.1 Describe, how would you simulate the operation of the travel agency based on the use of random number tables.
- Q.2 Simulate the arrival and serving of 12 clients and show the number of clients who receive a voucher (Use random number below to derive the arrival pattern and line 2 for serving time)

Random numbers

Line 1	03	47	43	73	86	36	96	47	36	61	46	98
Line 2	63	71	62	33	26	16	80	45	60	11	14	10

After this, please proceed with Illustration 43. The logic of the question remains the same; however, in this case, the starting time is taken as 8:00 AM instead of 0. Similar questions involving the arrival and servicing of 12 clients have been tested approximately four times in the CMA Final Strategic Cost Management exam, with marks ranging from 10 to 16. Simplified versions of these questions, involving the arrival and servicing of 5 clients, have been tested at the intermediate level for seven marks.

All the remaining illustrations are discussed in the subsequent videos. There is a 95% chance that questions for the exam will be tested from the first 6 questions we discussed.



4.8 Line Balancing

Questions For Classroom Discussion

Question 1

Table shows the time remaining (number of days until due date) and the work remaining (number of day's still required to finish the work) for 5 jobs which were assigned the letters A to E as they arrived to the shop. Sequence these jobs by priority rules viz.,

- FCFS - First Come First Served
- LCFS - Last Come First Served
- EDD - Early Due Date
- LS - Least Slack
- CR- Critical Ratio
- SPT - Shortest Processing Time
- LPT - Longest Processing Time

Job	Number of Days Until Due Date	Number of Days of Work Remaining
A	8	7
B	3	4
C	7	5
D	9	2
E	6	6

The following jobs have to be shipped a week from now. The week is having 5 Working Days

Job	A	B	C	D	E	F
Number of days of Work Remaining	2	4	7	6	5	3

Sequence the jobs according to priority rule

- Least Slack (LS)
- Critical Ratio (CR)

Question 2

In a factory, there are six jobs to perform, each of which should go through two machines A and B, in the order AB. The processing timings in hours for the jobs are given here. You are required to determine the sequence for performing the jobs that would minimize the total elapsed time, T. What is the value of T?

Job	Machine A	Machine B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

Question 3

Home Work- Previous Year Question 5 Marks

A company plans to fill four positions and it decides to conduct attitude test and interviews for the same. While the aptitude tests are conducted by the people from the clerical posts, the job interviews

are held by the personal from the management cadre. The job interviews immediately follow the aptitude test. The time required in minutes by each positions are given here

Position	P1	P2	P3	P4
Aptitude Test	100	110	140	120
Job Interview	70	90	80	110

If it is desired to minimise the waiting time of the management personnel, in what order the position filling be handled?

Illustration From Study Material

Illustration 38:

State the major two reasons for using simulation to solve a problem

A confectioner sells confectionery items. Past data of demand per week in hundred kilograms with frequency is given below:

Demand/Week	0	5	10	15	20	25
Frequency	2	11	8	21	5	3

Using the following sequence of random numbers, generate the demand for the next 10 weeks. Also find out the average demand per week.

Random numbers	35	52	13	90	23	73	34	57
	35	83	94	56	67	66	60	

Answer:

Table - I

Random No. Range Table for demand				
Demand per week	Frequency (f)	Probability ($p = f \div \Sigma f$)	Cumulative Probability	Range† of Random Nos.
0	2	.04	.04	00-03
5	11	.22	.26	04-25
10	8	.16	.42	26-41
15	21	.42	.84	42-83
20	5	.10	.94	84-93
25	3	.06	1.00	94-99
	$\Sigma f = 50$	1.00		

†As the given Random Nos. are of 2 digits, the ranges of Random Nos. has also been considered to have 2 digits only. Also the range of Random Nos. corresponds to cumulative probability values which lies between 0 & 1 and can be correlated as nos. between 00 and 99.

Table - II

Simulated Values for next 10 weeks		
Weeks	Random Nos.	Demand
1	35*	10*
2	52	15
3	13	5
4	90	20
5	23	5
6	73	15
7	34	10
8	57	15
9	35	10
10	83	15
Total	-	120

*From Table (I), Random No. 35 appears in the range of 26-41. Also the demand for this range is 10.
Average weekly demand = $120 / 10 = 12$

Illustration 39:

The manager of a book store has to decide the number of copies of a particular tax law book to order. A book costs Rs. 60 and is sold for Rs. 80. Since some of the tax laws change year after year, any copies unsold while the edition is not current must be sold for Rs. 30. From past records, the distribution of demand for this book has been obtained as follows:

Demand (No of copies)	15	16	17	18	19	20	21	22
Proportion	0.05	0.08	0.20	0.45	0.10	0.07	0.03	0.02

Using the following sequence of random numbers, generate the demand for 20 time periods(years).

Calculate the average profit obtainable under each of the courses of action open to the manager. What is the optimal policy?

14	02	93	99	18	71	37	30	12	10
88	13	00	57	69	32	18	08	92	73

Answer:

Random No. Range Table			
Demand	Probability	Cumulative Probability	Random No. Range
15	.05	.05	00-04
16	.08	.13	05-12
17	.20	.33	13-32
18	.45	.78	33-77
19	.10	.88	78-87
20	.07	.95	88-94
21	.03	.98	95-97
22	.02	1.00	98-99
Total	1.00	-	-

Calculation of demand and profit for next 20 years					
Year	Random Numbers	Expected demand	No. of books unsold if stock is		
			16*	17*	18*
1	14	17	-	-	1
2	02	15	1	2	3
3	93	20	-	-	-
4	99	22	-	-	-
5	18	17	-	-	1
6	71	18	-	-	-
7	37	18	-	-	-
8	30	17	-	-	1
9	12	16	-	1	2
10	10	16	-	1	2
11	88	20	-	-	-
12	13	17	-	-	1
13	00	15	1	2	3
14	57	18	-	-	-
15	69	18	-	-	-
16	32	17	-	-	1



17	18	17	-	-	1
18	08	16	-	1	2
19	92	20	-	-	-
20	73	18	-	-	-
Total			2	7	18

*Looking at the simulated demand pattern, these stock figures have been chosen to find out optimal course of action. Stock figures of 20 or more have not been considered because it is quite obvious that such figures will not give optimal course of action due to high losses for the unsold books.

Statement Showing Computation of Profit			
No. of Books order (n)	No. of Books sold in 20 years (n × 20 - Books unsold)	*Net Profit (Rs.)	Average Profit/Year (Profit ÷ 20)
15	15 × 20 = 300	Rs. 6000	Rs. 300
16	16 × 20 - 2 = 318	Rs. 6300 (318 × 20) - 2 × 30	Rs. 315
17	(17 × 20) - 7 = 333	Rs. 6450 (333 × 20) - 7 × 30	Rs. 322.5
18	(18 × 20) - 18	Rs. 6300 (342 × 20) - 18 × 30	Rs. 315

* Net Profit = No. of books sold × Rs. 20# - No. of books unsold × Rs. 30**

Selling price/book = Rs. 80, Cost/book = Rs. 60

Profit /book = 80 - 60 = Rs. 20

Selling price of any unsold book = Rs. 30

**Loss incurred/unsold book = Rs. 60 - Rs. 30 = Rs. 30

Since profit is maximum for 17 books order, the optimal policy is to order 17 books per year.

Illustration 40:

A Small retailer has studied the weekly receipts and payments over the past 200 weeks and has developed the following set of information:

Weekly Receipts (Rs.)	Probability	Weekly Payments (Rs.)	Probability
3000	0.20	4000	0.30
5000	0.30	6000	0.40
7000	0.40	8000	0.20
12000	0.10	10000	0.10

Using the following set of random numbers, simulate the weekly pattern of receipts and payments for the 12 weeks of the next quarter, assuming further that the beginning bank balance is Rs. 8000. What is the estimated balance at the end of the 12-weekly period? What is the highest weekly balance during the quarter? What is the average weekly balance for the quarter?

Random Numbers

For Receipts	03	91	38	55	17	46	32	43	69	72	24	22
For payments	61	96	30	32	03	88	48	28	88	18	71	99

According to the given information, the random number interval is assigned to both the receipts and the payments.

Answer:

Range of random numbers							
Receipt (Rs.)	Probability	Cumulative probability	Range	Payments (Rs.)	Probability	Cumulative probability	Range
3000	0.20	0.20	00-19	4000	0.30	0.30	00-29
5000	0.30	0.50	20-49	6000	0.40	0.70	30-69
7000	0.40	0.90	50-89	8000	0.20	0.90	70-89
12000	0.10	1.00	90-99	10000	0.10	1.00	90-99

Simulation of Data for a period of 12 weeks					
Week	Random No. for receipt	Expected Receipt (Rs.)	Random No. for payment	Expected Payment (Rs.)	Week end Balance (Rs.)
Opening Balance					8000
1	03	3000	61	6000	5000 (8000 + 3000 - 6000)
2	91	12000	96	10000	7000
3	38	5000	30	6000	6000
4	55	7000	32	6000	7000
5	17	3000	03	4000	6000
6	46	5000	88	8000	3000
7	32	5000	48	6000	2000
8	43	5000	28	4000	3000
9	69	7000	88	8000	2000
10	72	7000	18	4000	5000
11	24	5000	71	8000	2000
12	22	5000	99	10000	(3000)

Estimated balance at the end of 12th week = Rs. (3,000)

Highest balance = Rs. 7,000

Average balance during the quarter = $45,000/12 = \text{Rs. } 3,750$

Illustration 41:

An automobile production line turns out about 100 cars a day, but deviations occur owing to many causes. The production is more accurately described by the probability distribution given below:

Production/Day	Prob.	Production/Day	Prob.
95	0.03	101	0.15
96	0.05	102	0.10
97	0.07	103	0.07
98	0.10	104	0.05
99	0.15	105	0.03
100	0.20		
		Total	1.00

Finished cars are transported across the bay, at the end of each day, by ferry. If the ferry has space for only 101 cars, what will be the average number of cars waiting to be shipped, and what will be the



average number of empty space on the boat? Use following Random Numbers to simulate the data provided above - 20, 63, 46, 16, 45, 41, 44, 66, 87, 26, 78, 40, 29, 92, 21.

Answer:

Simulation of data of an Automobile Production line			
Production/day	Probability	Cumulative Probability	Random No. Range
95	0.03	0.03	00-02
96	0.05	0.08	03-07
97	0.07	0.15	08-14
98	0.10	0.25	15-24
99	0.15	0.40	25-39
100	0.20	0.60	40-59
101	0.15	0.75	60-74
102	0.10	0.85	75-84
103	0.07	0.92	85-91
104	0.05	0.97	92-96
105	0.03	1.00	97-99
	1.00		

Simulated data				
Day	Random No.	Production	No. of cars waiting to be shipped	No. of empty space on the boat
1	20	98	-	3
2	63	101	-	-
3	46	100	-	1
4	16	98	-	3
5	45	100	-	1
6	41	100	-	1
7	44	100	-	1
8	66	101	-	-
9	87	103	2	-
10	26	99	-	2
11	78	102	1	-
12	40	100	-	1
13	29	99	-	2
14	92	104	3	-
15	21	98	-	3
Total			6	18

Average no. of cars waiting to be shipped = $6/15 = 0.40$ per day

Average no. of empty space on the boat = $18/15 = 1.2$ per day

Illustration 42:

A book store wishes to carry 'Ramayana' in stock. Demand is probabilistic and replenishment of stock takes 2 days (i.e. if an order is placed on March 1, it will be delivered at the end of the day on March 3). The probabilities of demand are given below:

Demand (daily)	0	1	2	3	4
Probability	0.05	0.10	0.30	0.45	0.10

Each time an order is placed, the store incurs an ordering cost of Rs. 10 per order. The store also incurs a carrying cost of Rs. 0.50 per book per day. The inventory carrying cost is calculated on the basis of stock at the end of each day.

The manager of the bookstore wishes to compare two options for his inventory decision.

- Order 5 books when the inventory at the beginning of the day plus order outstanding is less than 8 books.
- Order 8 books when the inventory at the beginning of the day plus order outstanding is less than 8. Currently (beginning 1st day) the store has a stock of 8 books plus 6 books ordered two days ago and expected to arrive next day.

Using Monte-Carlo Simulation for 10 cycles, recommend, which option the manager, should choose.

The two-digit random numbers are given below:

89	34	70	63	61	81	39	16	13	73

Answer:

Demand	Probability	Cumulative Probability	Random No. Range
0	0.05	0.05	00-04
1	0.10	0.15	05-14
2	0.30	0.45	15-44
3	0.45	0.90	45-89
4	0.10	1.00	90-99

Option - A

Day	Random No.	Demand	Opening Stock	Ordered Quantity receipt	Closing Stock	Quantity for which Order Placed
1	89	3	8	-	5	-
2	34	2	5	6	9	-
3	70	3	9	-	6	0
4	63	3	6	-	3	5
5	61	3	3	0	0	-
6	81	3	0	5	2	5
7	39	2	2	-	0	5
8	16	2	0	5	3	-
9	13	1	3	5	7	-
10	73	3	7	-	4	5
					39	

Ordering cost 4×10	Rs. 40
Carrying cost 0.5×39	Rs. 19.50
Total Cost	Rs. 59.50



Option B

Day	R No.	Demand	Opening Stock	Ordered Quantity receipt	Closing Stock	Quantity for which Order placed
1	89	3	8	-	5	-
2	34	2	5	6	9	-
3	70	3	9	-	6	-
4	63	3	6	-	3	8
5	61	3	3	-	0	-
6	81	3	0	8	5	-
7	39	2	5	-	3	8
8	16	2	3	-	1	-
9	13	1	1	8	8	-
10	73	3	8	-	5	-
					45	

Ordering cost 2×10	Rs. 20.0
Carrying cost 0.5×45	Rs. 22.50
Total Cost	Rs. 42.50

Option 'B' is better because it has low Inventory cost.

Illustration 43:

After observing heavy congestion of customers over a period of time in a petrol station, Mr. Petro has decided to set up a petrol pump facility on his own in a nearby site. He has compiled statistics relating to the potential customer arrival pattern and service pattern as given below. He has also decided to evaluate the operations by using the simulation technique.

Arrivals		Services	
Inter-arrival time (minutes)	Probability	Service time (minutes)	Probability
2	0.22	4	0.28
4	0.30	6	0.40
6	0.24	8	0.22
8	0.14	10	0.10
10	0.10		

Assume:

- (i) The clock starts at 8:00 hours
- (ii) Only one pump is set up.
- (iii) The following 12 Random Numbers are to be used to depict the customer arrival pattern:
78, 26, 94, 08, 46, 63, 18, 35, 59, 12, 97 and 82.
- (iv) The following 12 Random Numbers are to be used to depict the service pattern:
44, 21, 73, 96, 63, 35, 57, 31, 84, 24, 05, 37

You are required to find out the

- (i) probability of the pump being idle, and
- (ii) Average time spent by a customer waiting in queue.

Answer:

Inter-arrival time				Service time			
Minutes	Probability	Cumulative probability	Range of Random No.	Minutes	Probability	Cumulative probability	Range
2	0.22	0.22	00-21	4	0.28	0.28	00-27
4	0.30	0.52	22-51	6	0.40	0.68	28-67
6	0.24	0.76	52-75	8	0.22	0.90	68-89
8	0.14	0.90	76-89	10	0.10	1.00	90-99
10	0.10	1.00	90 - 99	-	-	-	-

Sl.No.	Random No. for inter arrival time	Inter arrival time (Mins.)	Entry time in queue as per clock	Service start time as per clock	Random no for service time	Service time (Mins.)	Service end time as per clock	Waiting time of customer (Mins.)	Idle time (Mins.)
1	78	8	8.08	8.08	44	6	8.14	-	8
2	26	4	8.12	8.14	21	4	8.18	2	-
3	94	10	8.22	8.22	73	8	8.30	-	4
4	08	2	8.24	8.30	96	10	8.40	6	-
5	46	4	8.28	8.40	63	6	8.46	12	-
6	63	6	8.34	8.46	35	6	8.52	12	-
7	18	2	8.36	8.52	57	6	8.58	16	-
8	35	4	8.40	8.58	31	6	9.04	18	-
9	59	6	8.46	9.04	84	8	9.12	18	-
10	12	2	8.48	9.12	24	4	9.16	34	-
11	97	10	8.58	9.16	05	4	9.20	18	-
12	82	8	9.06	9.20	37	6	9.26	14	-
Total Time								150	12

Average time spent by the customer waiting in the queue = $150/12 = 12.50$ minutes

Probability of idle time of petrol station = Total idle time / Total Operating = $12/86 = 0.1395$
time of the Service Channel*

*Service End Time - 9.26 Hrs. Service Channel opened at 8.00 hrs. i.e. Total Time of the Service Channel = 1 hr. 26 Mins = 86 Mins.

Illustration 44:

A retailer deals in a perishable commodity. The daily demand and supply are variables. The data for the past 500 days show the following demand and supply:

Availability (Kg.)	Supply (No. of days)	Demand (Kg.)	Demand (No. of days)
10	40	10	50
20	50	20	110
30	190	30	200
40	150	40	100
50	70	50	40

The retailer buys the commodity at Rs. 20 per kg. and sells at Rs. 30 per kg. Any commodity remains at the end of the day, has no sales value. Moreover, the loss on unsatisfied demand is Rs. 8 per Kg. Given the following pair of random numbers, simulate 6 days sales, demand and profit: (31, 18) (63, 84) (15, 79) (07, 32) (43, 75) (81, 27). The first random number in the pair is that of supply and the second random number is for demand.

Answer:

Table-1: Probability Distribution (Supply)

Supply	Probability	Cum. Prob.	Range	Range of Random Nos. for simulation
10	$40/500 = 0.08$	0.08	0 - 0.08	00 - 07
20	$50/500 = 0.10$	0.18	0.08 - 0.18	08 - 17
30	$190/500 = 0.38$	0.56	0.18 - 0.56	18 - 55
40	$150/500 = 0.30$	0.86	0.56 - 0.86	56 - 85
50	$70/500 = 0.14$	1.00	0.86 - 1.00	86 - 99

Table-2: Probability distribution (Demand)

Demand	Probability	Cum. Prob.	Range	Range of Random Nos. for simulation
10	$50/500 = 0.10$	0.10	0 - 0.10	00 - 09
20	$110/500 = 0.22$	0.32	0.10 - 0.32	10 - 31
30	$200/500 = 0.40$	0.72	0.32 - 0.72	32 - 71
40	$100/500 = 0.20$	0.92	0.72 - 0.92	72 - 91
50	$40/500 = 0.08$	1.00	0.92 - 1.00	92 - 99

Table-3: Showing simulated data

Simulated data for supply			Simulated data for demand		
Day	Random No.	Supply (Kg.)	Day	Random No.	Demand (Kg.)
1	31	30	1	18	20
2	63	40	2	84	40
3	15	20	3	79	40
4	07	10	4	32	30
5	43	30	5	75	40
6	81	40	6	27	20

Table-4: Statement Showing Supply, Demand and Profit

Day	Supply	Demand	*Sales Revenue	Cost (II)	Loss due to unsatisfied demand (III)	Profit (Rs.)
(a)	(b)	(c)	(d)	(e) = (b) × Rs.20/kg	(f) = [(c)-(b)] × Rs.8/kg	(g) = (d)-(c)-(f)
1	30	20	600	600	-	Nil
2	40	40	1,200	800	-	400
3	20	40	600	400	160	40
4	10	30	300	200	160	-60**
5	30	40	900	600	80	220
6	40	20	600	800	-	-200**

* (1) Sales revenue = Demand × Selling price, when Demand < Supply

(2) Sales revenue = Supply × Selling price, when Demand > Supply

** Negative figures indicate loss

Illustration 45:

Using empirical data A process planner is working on plans for producing a new detergent. She wishes to simulate a raw material demand in order to plan for adequate materials - handling and storage facilities. On the basis of usage for a similar product introduced previously, she has developed a frequency distribution of demand in tons per day for a 2-month period. Use this data (shown below) to simulate the raw material usage requirements for 7 periods (days).

Demands, X (tons/ day)	10	11	12	13	14	15	Total = 60
Frequency (days)	6	18	15	12	6	3	

Answer:

The steps below correspond to those in Fig. 5-17.

- (1) Data are given in frequencies.
- (2) To formulate a probability distribution, divide each frequency by the total (60), for example, $6/60 = .10$ and $18/60 = .30$. Then formulate a cumulative probability distribution by successively summing the probability values.

Demand (tons/day)	Frequency (days)	Probability P(X)	Cumulative probability
10	6	0.10	0.10
11	18	0.30	$\downarrow (10 + 0.30) = 0.40$
12	15	0.25	0.65
13	12	0.20	0.85
14	6	0.10	0.95
15	3	0.05	
1.00	60	1.00	

- (3) Next, assign random - number intervals so that the number of values available to each class corresponds with the probability. Using 100 two - digit numbers (00-99), we assign 10 percent (00-09) to the first class, 30 percent (10-39) to the second class, and so on.

Demand (tons/day)	Probability P(X)	Corresponding Random Numbers
10	.10	00-09
11	.30	10-39
12	.25	40-64
13	.20	64-84
14	.10	85-94
15	.05	95-99
	1.00	

RN = 27

- (4) We obtained random numbers (RN) from column 1 of Appendix I (for convenience), so the first seven numbers are:

27 13 80 10 54 60 49

The first RN, 27, falls into the second class of the distribution and corresponds to a demand of 11 tons per day.

Random Number	27	13	80	10	54	60	49
Simulated Demand	11	11	13	11	12	12	12

- (5) This extremely small simulation yields a mean of $X = 11.7$ tons and a standard deviation of $s = .76$ tons. The expected value from the empirical probability distribution is $E(X) = [XP(X)] = 12.05$ tons, suggestion that the small sample size of only 7 periods has resulted in some error. A much larger sample should be simulated before the simulation results are used for making decisions. Note that the width of the random number "target" in each class corresponds exactly to the relative frequency of the class. This helps to ensure that the simulated results have the same type of distribution as the original data. This is more apparent in the graphic method where the vertical distances on the graph correspond to the relative frequencies of the respective classes.

Illustration 46:

Empirical data collected on the time required to weld a transformer bracket were recorded to the nearest $\frac{1}{4}$ minute, as shown in the accompanying table.

Weld Time (min)	Numbers of Observation
< .25	0
.25 < .75	24
.75 < 1.25	42
1.25 < 1.75	72
1.75 < 2.25	38
2.25 < 2.75	14
2.75 < 3.25	10

- Formulate a cumulative distribution in percentage terms.
- Graphs the frequency and cumulative distributions.
- A simulation is to be conducted using random numbers. What simulated weld times (to the nearest .25 minute) would result from the random numbers 25, 90, and 59?
- What proportion of the times exceed 2.0 minutes?

Answer:

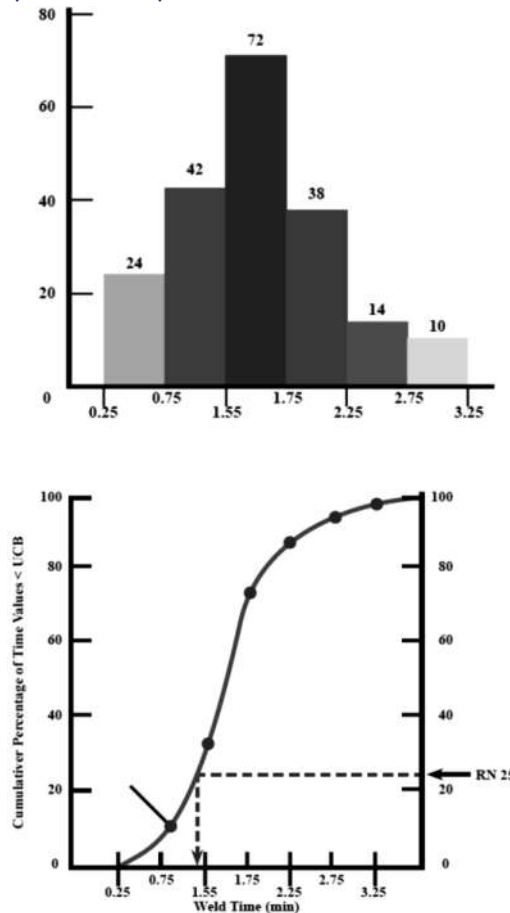
- Cumulative distributions are usually formulated on a scale where the cumulative percentage is "more than" or "less than" a corresponding X axis amount. We shall use a "less than" percentage and so will need to identify the upper- class boundaries (UCB) as the Y coordinates for the cumulative distribution.

Weld Time (Min)	Frequency In Numbers	Upper - Class Boundary (UCB)	Cumulative Number Of Times < UCB	Cumulative Percentage Of Time < UCB
< .25	0	.25	0	0
.25 < .75	24	.75	24	12
.75 < 1.25	42	1.25	66	33
1.25 < 1.75	72	1.75	138	69
1.75 < 2.25	38	2.25	176	88
2.25 < 2.75	14	2.75	190	95
2.75 < 3.25	10	3.25	200	100

- The frequency distribution is constructed by extending vertical lines from the class boundaries to the appropriate frequency level for the class. For the cumulative distribution, values of the



cumulative percentage of time < UCB are plotted at weld times corresponding to the UCB. For example, the frequency (12 percent) is plotted at UCB = .75 (as illustrated below).



(c) The simulated time for random number (RN) 25 is determined by entering the cumulative graph at 25 (as shown by the arrow) and proceeding horizontally to the curve and then down to the weld time. The resultant is a reading of 1.0 minute (rounded to the nearest .25 minutes). Times for random number 90 and 59 are 2.5 and 1.5 minutes, respectively. (A larger graph would lend more accuracy.)

(d) From the cumulative distribution, about 12 percent of the times exceed 2.0 minutes

Illustration 47:

How simulated times can be used to gain a knowledge of the interface of two assembly activities In an aircraft assembly operation, activities A precedes activity B, and inventory may accumulate between the two activities.

With the use of random numbers, a simulated sample of performance times yielded the values shown (minutes) in the accompanying table.



Activity A		Activity B	
Random Number	Time (min)	Random Number	Time
07	.3	63	.5
90	.8	44	.4
02	.2	30	.4

50	.5	98	.9
76	.6	30	.4
47	.5	72	.6
13	.3	58	.5
06	.3	96	.9
79	.7	37	.4

- (a) Simulated the assembly of six parts, showing idle time in activity B, waiting time of each part, and number of parts waiting. Note: omit the first random number of A so that activity B begins at time zero.
- (b) What was the average length of the waiting line ahead of B (in number of units)?
- (c) What was the average output per hour of the assembly line?

Answer:

- (a) Our interest lies in activity b, so we can set up a table (below) to show when parts arrive at B, how long it takes B, how long it takes B to work on them, and the resultant idle and waiting times:

Part Number	Part Available for Activity B at Time	Activity B Beginning Time	Activity B Ending Time	Activity B Idle Time	Waiting Time of Part	Number parts Waiting at B End time
1	-	0	.5	0	0	0
2	.8	.8	1.2		.3	0
3	1.0	1.2	1.6	0	.2	1
4	1.5	1.6	2.5	0	.1	1
5	2.1	2.5	2.9	0	.4	2
6	2.6	2.9	3.5*	0	.3	2
7	2.9				1.0 **	2
8	3.2					

* Total run time.

**Total waiting time.

Activity B begins at 0, and it takes .5 minute to complete the first part. B is then idle for .3 minute until part 2 arrives from A at .8 minutes. Part 2 takes .4 minute, so the ending time is .8 + .4 = 1.2 minutes. By this time part 3 has been waiting. 2 minute because it became available at .8 + .2 = 1.0 minute, but work could not be begun on it until 1.2 minutes. However, before activity B is finished on part 3 at 1.6 minutes, part 4 has arrived (at 1.0 + .5 = 1.5 minutes) and so one part is waiting. We continue systematically in this manner through part 6, noting that when it is finished at time were 3.5 minutes, there are two parts waiting, for their availability times were 2.9 minutes and 3.2 minutes, respectively.

- (b) The average length of the waiting line (that is, average inventory) ahead of B can be expressed in equation form as follows:

$$\begin{aligned}
 \text{Average inventory} &= \frac{\text{Total waiting time}}{\text{Total run time}} \\
 &= \frac{1.0 \text{ assembly minute}}{3.5 \text{ minutes}} \\
 &= 0.29 \text{ assembly}
 \end{aligned}$$

(c) Average output per hour:

$$\frac{6 \text{ unit}}{3.5 \text{ minutes}} \left(\frac{60 \text{ min}}{\text{hr}} \right) = 102.9 \text{ units / hr}$$

Illustration 48:

The Tit-Fit Scientific Laboratories is engaged in producing different types of high class equipment for use in science laboratories. The company has two different assembly lines to produce its most popular product 'Pressure'. The processing time for each of the assembly lines is regarded as a random variable and is described by the following distributions.

Process Time (minutes)	Assembly A1	Assembly A2
10	0.10	0.20
11	0.15	0.40
12	0.40	0.20
13	0.25	0.15
14	0.10	0.05

Using the following random numbers, generate data on the process times for 15 units of the item and compute the expected process time for the product. For the purpose, read the numbers vertically taking the first two digits for the processing time on assembly A1 and the last two digits for processing time on assembly A2.

4134	8343	3602	7505	7428
7476	1183	9445	0089	3424
4943	1915	5415	0880	9309

In the first stage, we assign random number intervals to the processing times on each of the assemblies.

Answer:

Computation of Random Interval for Processing Time

Process time Minutes	A1			A2		
	P _i	ΣP _i	Range	P _i	ΣP _i	Range
10	0.10	0.10	0-9	0.20	0.20	0-19
11	0.15	0.25	10-24	0.10	0.60	20-59
12	0.40	0.65	25-64	0.20	0.80	60-79
13	0.25	0.90	65-89	0.15	.095	80-94
14	0.10	1.00	90-99	0.05	1.00	95-99

Simulated date for 15 units

	Random No.	Process Time	Random No.	Process Time	Total
1	41	12	34	11	23
2	74	13	76	12	25
3	49	12	43	11	23
4	83	13	43	11	24
5	11	11	83	13	24
6	11	11	83	13	24
7	36	12	02	10	22
8	94	14	45	11	25
9	54	12	15	10	22

10	75	13	05	10	23
11	00	10	89	13	23
12	08	10	80	13	23
13	74	13	28	11	24
14	34	12	24	11	23
15	93	14	09	10	24
		182		167	349

Average Process time for

$$A1 = 182/15 = 12.13 \text{ Minutes}$$

$$A2 = 167/15 = 11.13 \text{ Minutes}$$

$$\text{For product} = 349/15 = 23.27 \text{ Minutes}$$

$$\text{Expected process time for the product} = 23.27 \text{ minutes } (12.13 + 11.13)$$

Illustration 49:

A businessman is considering taking over a certain new business. Based on past information and his own knowledge of the business, he works out the probability distribution of the monthly costs and sales revenues, as given here:

Cost (in Rs.)	Probability	Sales Revenue (Rs.)	Probability
17000	0.10	19000	0.10
18000	0.10	20000	0.10
19000	0.40	21000	0.20
20000	0.20	22000	0.40
21000	0.20	23000	0.15
		24000	0.05

Use the following sequences of random numbers to be used for estimating costs and revenues. Obtain the probability distribution of the monthly net revenue.

Sequence 1	82	84	28	82	36	92	73	91	63	29
	27	26	92	63	83	02	10	39	10	10
Sequence 2	39	72	38	29	71	83	19	72	92	59
	49	39	72	94	04	92	72	18	09	00

Answer:

Cost (Rs.)	Probability	Cumulative Probability	Random Range	Cost (Rs.)	Probability	Cumulative Probability	Random Range
17000	0.1	0.1	00-09	19000	0.1	0.1	00-09
18000	0.1	0.2	10-19	20000	0.1	0.2	10-19
19000	0.4	0.6	20-59	21000	0.2	0.4	20-39
20000	0.2	0.8	60-79	22000	0.4	0.8	40-79
21000	0.2	1.0	80-99	23000	0.15	0.95	80-94
				24000	0.05	1.00	95-99

Month	Random No. for Cost	Cost (Rs.)	Random No. for Sales	Cost (Rs.)	Monthly Net Revenue (Rs.)
1	82	21000	39	21000	-
2	84	21000	72	22000	1000

3	28	19000	38	21000	2000
4	82	21000	29	21000	-
5	36	19000	71	22000	3000
6	92	21000	83	23000	2000
7	73	20000	19	20000	-
8	91	21000	72	22000	1000
9	63	20000	92	23000	3000
10	29	19000	59	22000	3000
11	27	19000	49	22000	3000
12	26	19000	39	21000	2000
13	92	21000	72	22000	1000
14	63	20000	94	23000	3000
15	83	21000	04	19000	(2000)
16	02	17000	92	23000	6000
17	10	18000	72	22000	4000
18	39	19000	18	20000	1000
19	10	18000	09	19000	1000
20	10	18000	00	19000	1000
					35000

Average = $35000/20 = \text{Rs. } 1750$.

Illustration 50:

Table shows the time remaining (number of days until due date) and the work remaining (number of day's still required to finish the work) for 5 jobs which were assigned the letters A to E as they arrived to the shop. Sequence these jobs by priority rules viz., (a) FCFS, (b) EDD, (c) LS, (d) SPT and (e) LPT.

Job	Number days until due date	Number of day's of work remaining
A	8	7
B	3	4
C	7	5
D	9	2
E	6	6

Answer:

(a) **FCFS (First come first served):** Since the jobs are assigned letters A to E as they arrived to the shop, the sequence according to FCFS priority rule is A B C D E

(b) **EDD (Early due date job first) rule:** Taking into account the number of days until due date, the sequence of jobs as per EDD rules is

Job	B	E	C	A	D
No. of days units/due date	3	6	7	8	9

Here the job having earliest due date is sequenced first and the others are sequenced in ascending order of due date.

(c) **L.S. (Least slack) rule** also called as Minimum slack rule.

Calculation of slack:

Slack = (Number of days until due date) - (Number of days of work remaining)

Job	No. of days until/due date	No. of days of work remaining	Slack (Days)
A	8	7	$8 - 7 = 1$
B	3	4	$3 - 4 = -1$
C	7	5	$7 - 5 = 2$
D	9	2	$9 - 2 = 7$
E	6	6	$6 - 6 = 0$

Sequence:

Job	B	E	A	C	D
Slack -	1	0	1	2	7

Here the jobs are sequenced in ascending order of magnitude of their respective slacks.

- (d) SPT (Shortest Processing Time job first) also referred as SOT (Shortest Operation time job First) rule or MINPRT (Minimum Processing time job first) rule. As per this rule, jobs are sequenced in ascending order of magnitude of their respective processing time.

Sequence:

Job	D	B	C	E	A
Processing Time (Days)	2	4	5	6	7

- (e) LPT (Longest Processing time job first) also referred to as LOT (Longest operation time job first) rule.

As per this rule jobs are sequenced in descending order of magnitude of their respective processing times.

Sequence:

Job	A	E	C	B	D
Processing Time (Days)	7	6	5	4	2

Illustration 51:

The following jobs have to be shipped a week from now (week has 5 working days)

Job	A	B	C	D	E	F
Number of days of work remaining	2	4	7	6	5	3

Sequence the jobs according to priority established by (a) least slack rule (b) critical ratio rule.

Answer:

- (a) Calculation of slack:

Number of days until due date is 1 week i.e. 5 days for all jobs

Job (1)	No. of days until/due date (2)	No. of day of work remaining (3)	Slack (Days) (4) = (2) - (3)
A	5	2	3
B	5	4	1
C	5	7	- 2
D	5	6	- 1
E	5	5	0
F	5	3	2

Sequence:

Job	C	D	E	B	F	A
Slack (Days) -	2	-1	0	1	2	3

Jobs are sequenced in ascending order of magnitude of respective slack values.

(b) Calculation of Critical ratio:

$$= \frac{\text{Due date} - \text{Date Now}}{\text{Lead Time Remaining}} = \frac{\text{DD} - \text{DN}}{\text{LTR}} = \frac{\text{Available time till due date}}{\text{Operation time still needed to complete the job}}$$

Critical ratio for job A = $5/2 = 2.5$

Critical ratio for job B = $5/4 = 1.25$

Critical ratio for Job C = $5/7 = 0.71$

Critical ratio for job D = $5/6 = 0.83$

Critical ratio for job E = $5/5 = 1.0$

Critical ratio for job F = $5/3 = 1.67$

Job having least critical ratio is given the first priority and so on.

Sequence:	C	D	E	B	F	A
Critical Ratio:	0.71	0.83	1.0	1.25	1.67	2.5

Illustration 52:

In a factory, there are six jobs to perform, each of which should go through two machines A and B, in the order AB. The processing timings (in hours) for the jobs are given here. You are required to determine the sequence for performing the jobs that would minimise the total elapsed time, T. What is the value of T?

Job	Machine A	Machine B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

Answer:

- (a) The least of all the times given in the table is for job 6 on machine B. So, perform job 6 in the end. It is last in the sequence. Now delete this job from the given data.
- (b) Of all timings now, the minimum is for job 3 on machine A. So, do the job 3 first.
- (c) After deleting job 3 also, the smallest time of 3 hours is for job 1 on machine B. Thus, perform job 1 in the end (before job 6).
- (d) Having assigned job 1, we observe that the smallest value of 4 hours is shared by job 2 on machine A and job 5 on machine B. So, perform job 2 first and job 5 in the end.
- (e) Now, the only job remaining is job 4, it shall be assigned the only place left in the sequence. The resultant sequence of jobs is, therefore, as follows:

3	2	4	5	1	6

This sequence is the optimal one. The total elapsed time, T, is obtained in Table 2.8.16 as equal to 36 hours

Table: Calculation of Total Elapsed Time (T)

Job	Machine A		Machine B	
	In	Out	In	Out
3	0	2	2	8
2	2	6	8	16

4	6	11	16	22
5	11	20	22	26
1	20	27	27	30
6	27	35	35	36

As shown in this table, the first job, job 3, starts at time 0 on the machine A and is over by time 2, when it passes to machine B to be worked on till time 8. The job 2 starts on the machine A at time 2 as the machine is free at that time. It is completed at time 6 and has to wait for 2 hours before it is processed on machine B, starting at time 8 when this machine is free. Similarly, the various jobs are assigned to the two machines and the in and out times are obtained.

THEORY QUESTIONS

Question 1. What are the applications of Operations Research?

Six Possible Alternative Questions:

1. How does operations research contribute to national planning and budgeting?
2. What are the applications of operations research in the defence sector?
3. How do industrial companies benefit from operations research in plant location and inventory control?
4. In what ways does operations research aid research and development projects?
5. How does operations research influence business decision-making under competition?
6. What role does operations research play in optimizing agricultural and irrigation projects?

Applications of Operations Research

National Planning and Budgeting:

Operations research helps countries like India meticulously prepare five year plans and annual budgets. For example, forecasting national income and expenditure ensures efficient allocation of resources for projects like the Delhi Metro expansion, aiding urban transportation planning. By estimating Gross National Product (GNP), Gross Domestic Product (GDP), population, and employment rates, governments can make informed decisions to drive economic growth.

Defence Service Operations:

In the defence sector, optimizing cost and time for projects, such as the development of the Advanced Medium Combat Aircraft (AMCA), is critical. Operations research assists in tender evaluation for technology and equipment, and strategizing defence supplies during war and peace. Effective maintenance and replacement of equipment, coupled with accurate threat analysis, ensure operational readiness. The Indian Navy's planning of supply depots and transportation logistics during mobilization is a prime example.

Industrial Fields:

Manufacturers like Tata Steel use operations research to optimize plant locations, financial planning, and product development. Streamlining inventory control, maintenance management, and personnel incentives ensures efficient production and cost savings. Operations research also aids in facility planning and factory layout, improving overall productivity.

Research & Development and Engineering:

In R&D, operations research facilitates technology forecasting and project management. For instance, Bharat Electronics Limited (BEL) uses operations research to evaluate and manage technology projects. Effective systems evaluation, tender preparation, and value engineering ensure that projects meet quality standards and are completed on time.

Business Management and Competition:

Corporations like Reliance Industries rely on operations research for decision-making under risk and uncertainty. This includes selecting business areas, forming business strategies, and determining optimal advertisement expenditures. Operations research techniques such as market analysis and sales force optimization help companies stay competitive and maximize returns on capital investments.

Agriculture and Irrigation:

Operations research supports the management of largescale projects like the Narmada Valley Development Project, optimizing the construction of dams and distribution of irrigation canals. By determining the best locations for supply points of seeds and fertilizers, and collection points for agricultural outputs, operations research helps improve agricultural efficiency and yields.

Education and Training:

Operations research is instrumental in planning the education system. For example, the Ministry of Human Resource Development uses it to optimize the number and locations of schools, determine the student teacher ratio, and plan financial outlays. Operations research ensures efficient utilization of resources in setting up examination centers and supplying educational materials.

Public Works Department:

Public works projects, such as the construction of bridges like the BandraWorli Sea Link, benefit from operations research in time and cost control. Estimating project timelines, selecting machinery, and preparing budgets are all enhanced through operations research, ensuring timely project completion and budget adherence.

- Mnemonic: "No Dogs In Red Boots Are Eagerly Preparing Hot Meals"



This sentence helps you remember the first letter of each major sector:

Sector	Mnemonic Word	Explanation
National Planning and Budgeting	No	"National" starts with N
Defence Service Operations	Dogs	"Defence" starts with D
Industrial Field	In	"Industrial" starts with I
R&D and Engineering	Red	"Research" starts with R
Business Management and Competition	Boots	"Business" starts with B
Agriculture and Irrigation	Are	"Agriculture" starts with A
Education and Training	Eagerly	"Education" starts with E
Public Works Department	Preparing	"Public" starts with P
Transportation and Communication	Hot	"Transportation" starts with T
Home Management and Budgeting	Meals	"Home" starts with H

Objectives of Production Planning and Control

Question 2. What are the objectives of Production planning and Control

Five Alternative Questions:

1. What are the primary objectives of production planning and control in manufacturing industries?
2. How does PPC assist in the efficient utilization of raw materials and labor in a company?
3. Explain the role of production planning and control in handling customer queries and order changes.
4. How does PPC contribute to maintaining stock levels and controlling inventory in an organization?
5. Describe the importance of preparing route sheets and schedules in the production process.

Production planning and control (PPC) is often seen as the heartbeat of any production operation, working behind the scenes to ensure that products are delivered on time to customers or inventory, in line with a well-planned schedule.

Objectives of Production Planning and Control

At its core, PPC aims to boost the company's profits by satisfying customers through timely deliveries. This is achieved by mapping out the routes and schedules for work, optimizing the use of raw materials, labor, and machines to ensure smooth plant operations.

Key Functions of Production Planning and Control:

1. **Analysing Orders:**
 - **Example:** Tata Motors meticulously analyzes orders to determine the raw materials and parts necessary for vehicle production. This ensures a seamless manufacturing process.
2. **Answering Customer and Sales Queries:**
 - **Example:** Samsung Electronics utilizes PPC to handle customer and sales inquiries about the status of their orders, ensuring transparency and satisfaction.
3. **Assisting Costing Departments:**
 - **Example:** Unilever's PPC aids the costing department in making accurate cost estimates for their diverse range of consumer goods, keeping everything financially efficient.
4. **Supporting HR in Manpower Planning:**
 - **Example:** Infosys uses PPC to effectively plan and assign employees to specific projects, optimizing the use of human resources.
5. **Controlling Stock of Finished Products:**
 - **Example:** Maruti Suzuki manages its finished car inventory to match market demand, avoiding overproduction and ensuring efficient stock control.
6. **Determining Necessary Tools for Manufacturing:**
 - **Example:** Bharat Heavy Electricals Limited (BHEL) identifies the essential tools needed for manufacturing turbines and heavy machinery, ensuring operational efficiency.
7. **Directing and Controlling Material Movement:**
 - **Example:** Hindustan Unilever controls the flow of materials through the production process of its FMCG products, ensuring smooth operations.
8. **Initiating Changes in Orders:**
 - **Example:** Flipkart adjusts orders as requested by customers during processing, enhancing customer satisfaction.
9. **Issuing Requisitions for Material Purchase:**
 - **Example:** Reliance Industries efficiently issues requisitions for purchasing the materials required for various industrial operations.

10. **Issuing Requisitions for Tool Manufacture:**
 - **Example:** Larsen & Toubro requests the manufacture of tools and parts necessary for construction projects, ensuring timely project completion.
11. **Keeping Up-to-Date Records:**
 - **Example:** Tata Steel maintains accurate records of schedules and in-process materials, enhancing production efficiency.
12. **Maintaining Stock Levels:**
 - **Example:** Mahindra & Mahindra effectively maintains stock levels of materials and parts for automotive production, avoiding delays.
13. **Notifying Sales and Accounting of Order Acceptance:**
 - **Example:** Wipro keeps sales and accounting departments informed about the feasibility and acceptance of IT service orders, ensuring smooth workflows.
14. **Preparing Route Sheets and Schedules:**
 - **Example:** Godrej Consumer Products creates detailed route sheets and schedules for the sequence of operations needed to produce its consumer goods.
15. **Production of Work Orders:**
 - **Example:** Tata Consultancy Services (TCS) produces work orders to kickstart software development projects, ensuring timely project initiation.
16. **Evaluating Progress and Initiating Corrective Actions:**
 - **Example:** Bajaj Auto reviews the progress of motorcycle production and takes corrective action if necessary to stay on schedule.
17. **Receiving Orders from Customers:**
 - **Example:** Amazon India efficiently processes and handles customer orders for a wide variety of products, enhancing customer experience.
18. **Revising Plans for Production Activities:**
 - **Example:** Ashok Leyland revises production plans when original schedules cannot be met, especially for rush orders of commercial vehicles.

Production Control Functions

Question 3. What are the Production Control Functions?

Four Alternative Essay Questions:

1. What are the critical functions of production control in manufacturing, and how do they contribute to operational efficiency?
2. How does effective production planning and control impact the overall success of a company?
3. Discuss the role of inspection in maintaining product quality within the production control framework.
4. Explain the importance of follow-up in the production control process and its impact on meeting production targets.

Production Control Functions

Production control is the heartbeat of any manufacturing operation. It ensures that every stage of the production process runs smoothly, meeting the standards and timelines set.

Key Functions of Production Control:

1. **Planning Production Operations:**
 - **Example:** At Ford Motor Company, detailed planning of production operations is essential to streamline the assembly line and ensure every component is available when needed, optimizing the workflow and minimizing delays.

2. Routing:

- **Example:** At Nike, the routing function lays out the specific path each sneaker takes through the manufacturing process, detailing the order in which operations like cutting, stitching, and finishing will be carried out.

3. Scheduling:

- **Example:** Toyota's just-in-time (JIT) production method involves meticulous scheduling to determine the exact quantity of work to be done at each stage and fixing precise timetables for operations, ensuring efficiency and minimizing waste.

4. Dispatching:

- **Example:** In Amazon's fulfillment centers, dispatching involves issuing orders for picking, packing, and shipping products, ensuring that customer delivery targets are met swiftly and accurately.

5. Follow-up:

- **Example:** At Tata Steel, follow-up processes include tracking production progress to ensure operations align with predetermined plans and standards, identifying any variances, and implementing corrective measures as needed.

6. Inspection:

- **Example:** Samsung's quality control involves regular inspections of their electronic products to ensure they meet the company's high standards before reaching consumers.

Mnemonic: "Please Remember Smart Decisions Fuel Industry" (PRSDFI)

This mnemonic helps you recall the **six core functions** of production control:

Mnemonic Letter	Function	Description
P	Planning	Planning the production operations in detail
R	Routing	Laying down the path and order of operations
S	Scheduling	Establishing quantity and timetable for operations
D	Dispatching	Issuing orders and ensuring time targets are met
F	Follow-up	Checking progress and identifying variances from standards
I	Inspection	Conducting check-ups to ensure high product quality

Detailed Breakdown

i. Planning

Planning the production operations in detail

Example: Deciding how many units to produce in the next quarter.

ii. Routing

Laying down the path for the work to follow and the order in which the various operations will be carried out

Example: Defining the sequence—cutting → welding → painting.

iii. Scheduling

Establishing the quantity of work to be done, and fixing the time table for performing the operations

Example: 500 units to be completed in 10 days.

iv. Dispatching

Issuing the necessary orders, and taking necessary steps to ensure that the time targets set in the schedules are effectively achieved

Example: Sending work orders to the shop floor and ensuring machines are ready.

v. Follow-up

Taking necessary steps to check up whether work proceeds according to predetermined plans and how far there are variances from the standards set earlier

Example: Reviewing daily progress reports and adjusting shifts if needed.

vi. **Inspection**

Conducting occasional check-ups of the products manufactured or assembled to ensure high quality of the production

Example: Random sampling of finished goods for quality testing.

Question 4. Basic Types of Production Control

Four Alternative Essay Questions:

1. How do different types of production control enhance efficiency in various industries?
2. Discuss the role of block control and flow control in maintaining production consistency.
3. Explain the importance of special project control in large-scale construction projects.
4. How does batch control ensure quality and consistency in the food processing industry?

Production control is essential to managing the flow of production in various industries. There are six types of production control, each tailored to specific industry needs.

1. **Block Control**

This type of control is prevalent in textiles and book and magazine printing. Industries employ block control to keep materials separated, which is crucial for maintaining order and avoiding mix-ups.

- **Example:** In the textile industry, companies like Arvind Limited use block control to manage different batches of fabric, ensuring that designs and colors remain consistent across production runs.

2. **Flow Control**

Flow control is commonly applied in industries like chemicals, petroleum, glass, and some areas of food manufacturing and processing. The production planning and control department oversees the rate of work flow into and out of the system. This method is more prevalent in continuous production systems, where routing and scheduling are established before production begins.

- **Example:** Indian Oil Corporation uses flow control to manage the continuous production of petroleum products, ensuring a balanced and sequenced production line.

3. **Load Control**

Load control is typically found wherever a particular bottleneck machine exists in the manufacturing process. This control type ensures that the bottleneck does not impede the overall production flow.

- **Example:** In the automotive industry, Mahindra & Mahindra employs load control to manage bottlenecks in the assembly line, optimizing the use of critical machinery to maintain steady production.

4. **Order Control**

Order control is common in companies with intermittent production systems, also known as job-lot shops. Orders come in for different quantities and products, requiring production planning and control to be based on individual orders.

- **Example:** In the aerospace industry, Hindustan Aeronautics Limited uses order control to manage custom aircraft component orders, ensuring each order meets specific customer requirements.

5. **Special Project Control**

Special project control is necessary for projects like constructing bridges, office buildings, schools, colleges, universities, hospitals, and other construction projects. A dedicated team or individual keeps close contact with the work, overseeing tooling and scheduling.

- **Example:** L&T Construction uses special project control for large-scale infrastructure projects, ensuring close supervision and timely completion.

6. Batch Control

Batch control is frequently found in food processing industries. Production control in batch systems operates with a set of predefined rules to manage the production process.

- **Example:** Amul employs batch control to manage the production of dairy products, ensuring consistency and quality across different production batches.
- **Mnemonic: "Big Friendly Lions Often Show Bravery" (B-F-L-O-S-B)**
- This mnemonic helps you remember the six types:

Mnemonic Letter	Type of Control	Industry Example
B	Block Control	Textiles, Printing (Books & Magazines)
F	Flow Control	Chemicals, Petroleum, Glass, Food Processing
L	Load Control	Any industry with bottleneck machines
O	Order Control	Job-lot shops, Intermittent production systems
S	Special Project Control	Construction (Bridges, Schools, Hospitals)
B	Batch Control	Food Processing, Pharmaceuticals

• Detailed Breakdown

i. Block Control

- Most prominent in textiles and book/magazine printing. Necessary to keep things separated.
Example: Keeping different fabric types or magazine editions separate during printing.

ii. Flow Control

- Applied in chemicals, petroleum, glass, and food processing. Routing and scheduling are done when the plant is laid out.
Example: A glass factory with a continuous production line where molten glass flows through stages.

iii. Load Control

- Found wherever a bottleneck machine exists in manufacturing.
Example: A CNC machine that slows down the entire production line due to limited capacity.

iv. Order Control

- Common in job-lot shops with intermittent production. Control is based on individual orders.
Example: A custom furniture shop receiving varied orders for tables, chairs, and cabinets.

v. Special Project Control

- Used in construction projects. A man or team stays in close contact with the work.
Example: A site engineer overseeing the construction of a hospital, adjusting plans daily.

vi. Batch Control

- Found in food processing industries. Operates with a set of batches.
Example: A bakery producing 500 loaves of bread in one batch, then switching to cookies.

Work Study, Method Study, Motion Study, Time Study

Question 5. What is Time Study, Work Study and Method Study

Alternative Essay Questions:

1. How do time study, work study, and method study contribute to improving production efficiency in industries?
2. Discuss the role of method study in developing efficient procedures and reducing operational costs.
3. Explain the importance of work study in optimizing the use of resources in a manufacturing environment

What is Work Study?

Work Study is a systematic examination of work systems to improve productivity and efficiency.

It consists of two major branches:

- **Method Study** - *How the work is done*
- **Time Study** - *How long the work takes*

1. Time Study

Time Study is the technique of recording the time taken to perform a job and setting a standard time for it.

Purpose:

- Identify time wastage
- Set performance benchmarks
- Improve scheduling and planning

Example:

A worker takes 12 minutes to assemble a bicycle wheel. After studying 10 cycles, the average time is 10 minutes. This becomes the **standard time** for future planning.

2. Method Study

Method Study is the systematic recording and critical examination of existing and proposed ways of doing work.

Purpose:

- Eliminate unnecessary movements
- Simplify tasks
- Improve layout and process

Example:

In a packaging unit, workers walk 5 meters to get boxes. By placing boxes closer, walking is eliminated—saving time and effort.

3. Motion Study

Motion Study involves analyzing the movements of workers or machines to improve efficiency.

Purpose:

- Reduce fatigue
- Improve ergonomics
- Increase speed and safety

4. Example:

A cashier reaches across the counter 50 times an hour. By rearranging the workspace, all tools are within arm's reach—reducing strain and increasing speed.

Applications of Linear Programming

Question 6. What are the applications of Linear Programming?

1. How does linear programming contribute to optimizing production schedules in manufacturing industries?
2. Discuss the role of linear programming in resource allocation within management practices.
3. Explain the applications of linear programming in environmental protection and urban development.
4. How is linear programming used in the agricultural sector for farm planning?
5. Describe the benefits of using linear programming for portfolio selection in financial management.



6. What are the non-industrial applications of linear programming, and how do they contribute to societal development?

Linear programming (LP) has become one of the most widely used techniques in managerial decision making across business, industry, and many other fields. Let's delve into how LP is applied in various domains:

1. Industrial Applications

Linear programming is extensively used to solve a variety of industrial problems, with the general objective of determining a plan for production and procurement within a given time frame. It ensures that all demand requirements are met without violating any constraints.

Examples of Industrial Applications:

- **Product Mix Problem:** Coca-Cola uses LP to determine the optimal mix of various beverages to maximize profit while meeting demand.
- **Production Scheduling:** Maruti Suzuki uses LP to schedule production runs efficiently, ensuring that different car models are produced in optimal quantities.
- **Blending Problems:** Oil refineries like Indian Oil Corporation use LP to determine the optimal blend of crude oils to produce different products such as gasoline, diesel, and jet fuel.
- **Transportation Problems:** Tata Steel uses LP to minimize transportation costs while delivering steel to various locations.
- **Communication Industry:** Companies like Bharti Airtel use LP to optimize their network facilities for transmission, switching, and relaying.

2. Management Applications

Linear programming is also crucial in various management decisions, aiding in optimizing resources and strategies.

Examples of Management Applications:

- **Portfolio Selection:** Mutual funds like SBI Mutual Fund use LP to select the best portfolio mix that maximizes returns while minimizing risk.
- **Profit Planning:** Infosys employs LP for profit planning, ensuring resource allocation aligns with projected profits.
- **Media Selection:** Hindustan Unilever uses LP to allocate its advertising budget across different media to maximize reach and effectiveness.

3. Miscellaneous Applications

LP is not confined to industrial and management applications; it finds use in numerous other fields.

Examples of Miscellaneous Applications:

- **Farm Planning:** Farmers use LP to determine the optimal mix of crops and livestock that maximize profit based on available resources.
- **Diet Problems:** Hospitals use LP to create the most economical diet plans for patients, balancing nutritional requirements and costs.
- **Airline Routing:** Airlines like Indigo use LP to determine the most efficient flight routes and schedules.

4. Administrative Applications

Linear programming helps in optimizing the use of resources in administrative tasks.

Examples of Administrative Applications:

- **Optimal Resource Usage:** Government agencies use LP to allocate manpower, machinery, and materials effectively in public projects.

5. Non-Industrial Applications

LP techniques can be applied beyond industrial settings to areas like agriculture, environmental protection, and urban development.

Examples of Non-Industrial Applications:

- **Environmental Protection:** Organizations use LP to design optimal strategies for reducing pollutants and managing waste.
- **Urban Development:** City planners use LP to determine the best locations for facilities such as hospitals, schools, and parks.

6. Further Applications

Linear programming also plays a role in various other specialized applications.

Examples of Further Applications:

- **Structural Design:** Architects use LP to design structures that maximize space and material efficiency.
- **Balancing Assembly Lines:** Companies like Mahindra & Mahindra use LP to balance their assembly lines, ensuring smooth and efficient production.
- **Quick Recap Table**

Mnemonic	Application Area
I	Industrial Applications
M	Management Applications
M	Miscellaneous Applications
A	Administrative Applications
Not	Non-Industrial Applications
Father	Further Applications

Key Concepts in Linear Programming

Question 7.

1. How do feasible, basic feasible, and optimal feasible solutions differ in the context of linear programming?
2. Discuss the significance of slack and surplus variables in linear programming and provide examples.
3. Explain the concept of a degenerate solution in linear programming and its potential implications in real-world applications.

- **Feasible Solution:** A feasible solution satisfies all the non-negative restrictions of the general Linear Programming Problem (L.P.P). It adheres to all the given constraints, ensuring the solution is viable.
Example: In optimizing warehouse space, a feasible solution would allocate resources without exceeding the space constraints while meeting all storage needs.
- **Basic Feasible Solution:** This is a feasible solution that also satisfies the basic solution criteria in an L.P.P. It is a starting point in the solution space that meets the conditions of a basic solution.
Example: For a factory producing multiple products, a basic feasible solution would ensure that each production line is utilized efficiently within its capacity constraints.
- **Optimal Feasible Solution:** An optimal feasible solution maximizes or minimizes the objective function of the L.P.P while being a basic feasible solution.

Example: In maximizing profits for a company like Reliance Industries, an optimal feasible solution would determine the best mix of products to produce and sell within the constraints of production capacity and market demand.

- **Degenerate Solution:** A basic solution where one or more of the basic variables equal zero. This can occur in situations where multiple constraints intersect at a single point in the solution space.
Example: In transportation logistics, a degenerate solution might occur if several routes converge at a hub with limited capacity, resulting in some routes not being fully utilized.
- **Slack Variables:** Slack variables are added to constraints in "less than or equal to" ($\leq$) form to convert them into equality equations.
Example: If a bakery needs to ensure that the total production time of cakes and cookies does not exceed 500 hours, the constraint $2x_1 + 3x_2 \leq 500$ can be written as $2x_1 + 3x_2 + S_1 = 500$, where S_1 is the slack variable representing unused time.
- **Surplus Variables:** Surplus variables are subtracted from constraints in "more than or equal to" ($\geq$) form to convert them into equality equations.
Example: If a factory must produce at least 100 units of a product, the constraint $3x_1 + 4x_2 \geq 100$ can be written as $3x_1 + 4x_2 - S_2 = 100$, where S_2 is the surplus variable representing the excess over 100 units.

Summary Table

Concept	Role in LP
Slack Variable	Converts $\leq$ constraints to equations; shows unused resources
Surplus Variable	Converts $\geq$ constraints to equations; shows excess over minimum
Artificial Variable	Temporarily added to help start Simplex when no BFS exists
Big M Method	Penalizes artificial variables to remove them from final solution
Simplex Table	Tabular tool for performing iterations and tracking optimization steps

Primal and Dual Linear Programming

Question 8.

1. Distinguish between Primal and Dual of Linear Programming?
2. What Are Primal and Dual Problems?

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 .

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Concept Book: Primal & Dual in Linear Programming

In Linear Programming, **every problem (Primal)** has a **corresponding problem (Dual)**. They are **mirror images** of each other, and solving one gives insights into the other.

1. Primal Problem

Definition:

The **original Linear Programming problem** is called the **Primal**.

Form:

- Usually involves **maximizing** or **minimizing** an objective function.
- Subject to **constraints** ($\leq$, $\geq$, or $=$) and **non-negativity** conditions.

Example:

Maximize $Z = 10x_1 + 8x_2$ Subject to: $2x_1 + 3x_2 \leq 30$
 $4x_1 + 5x_2 \leq 50$
 $x_1, x_2 \geq 0$

2. Dual Problem

Definition:

The **Dual** is derived from the **Primal** by transforming its constraints and objective.

Key Rules:

- **Maximization** $\leftrightarrow$ **Minimization**
- **Constraints** $\leftrightarrow$ **Variables**
- $\leq \leftrightarrow \geq$
- Coefficients of constraints become coefficients in the dual objective function.

◊ **Dual of the Above Example:**

Minimize $Z' = 30y_1 + 50y_2$
 Subject to: $2y_1 + 4y_2 \geq 10$,
 $3y_1 + 5y_2 \geq 8$
 $y_1, y_2 \geq 0$

Summary Table

Concept	
Primal	Original LP problem
Dual	Derived from primal; flips roles of constraints
Use	Solving one gives insights into the other
Benefit	Helps in sensitivity analysis and economic value

Scheduling and Routing

Question 9.

1. "What is scheduling in production planning and control? Explain its importance and relationship with routing using suitable examples."
2. "Describe the role of scheduling in efficient production management. How does it complement routing?"
3. "Explain how scheduling helps in balancing workload and ensuring timely completion of production tasks. Use examples to support your answer."

Scheduling

Scheduling is a crucial function in production planning and control, coming right after routing. It determines the start and completion times for each operation, ensuring that every machine and operator is engaged efficiently, without overburdening them. Essentially, scheduling figures out how long each step in the production process will take, as well as the time needed for the entire series of operations.

Example: Imagine a bakery that needs to bake various types of bread, cakes, and pastries. Scheduling helps the bakery decide when to start mixing dough, when to put items in the oven, and when to start decorating, ensuring that the bakery operates smoothly and all items are ready on time.

Key Points:

- **Efficiency:** Engages every machine and operator for maximum efficiency.
- **Timeliness:** Ensures operations start and finish on time.
- **Balance:** Avoids overburdening any part of the production system.

Relationship Between Routing & Scheduling

Routing	Scheduling
Defines sequence of operations	Determines timing for each operation
Specifies tools, equipment, personnel	Allocates start and finish times
Is a prerequisite for scheduling	Informs routing with time schedules
Focuses on efficiency of path	Focuses on efficiency of time usage

Key Insight:

Routing and Scheduling are **interconnected** and **interdependent**. They must work **together** for effective production planning and control.

Example

Imagine a factory producing custom furniture:

- **Routing:**
 1. Cutting → 2. Shaping → 3. Polishing → 4. Packaging
- **Scheduling:**
 1. Cutting: 9:00-10:00 AM
 2. Shaping: 10:00-11:30 AM
 3. Polishing: 11:30 AM-1:00 PM
 4. Packaging: 1:00-2:00 PM

Together, they ensure the product is made **efficiently and on time**.

Key Conclusion

- **Routing and Scheduling are complementary**
- Both are essential for **maximum production efficiency**
- Without scheduling, routing lacks **timing clarity**
- Without routing, scheduling lacks **operational structure**

Concept Book: Lean Operations -

Question 10.

1. "What are priority rules in lean operations? Explain the different types of priority rules and discuss how they help improve scheduling efficiency in production systems."

Smart scheduling starts with choosing the right rule for the right job.

What Are Priority Rules?

Priority rules are guidelines used to decide **which job to process next** in a production system. They help improve **efficiency**, **reduce delays**, and **maximize resource utilization**.

Common Priority Rules

1. **First Come First Served (FCFS)**
 - Jobs are processed in the **order they arrive**.
 - Simple and fair
 - May not be optimal for urgent or short jobs
2. **Shortest Operations Time (SOT) / Shortest Processing Time (SPT)**
 - Process jobs with the **shortest completion time** first.
 - Minimizes average job waiting time
 - Longer jobs may get delayed
3. **Early Due Date (EDD)**
 - Process jobs based on **earliest due dates**.
 - Helps meet delivery deadlines

- Ignores job size or urgency

4. Least Slack (LS)

- Process jobs with the **least slack time** left.
- Prioritizes jobs at risk of delay
- Requires accurate time estimates
- Slack = Number of days until Due Date - Number of days of work Remaining

5. Critical Ratio (CR)

- Process jobs with the **lowest critical ratio**.

Formula:

- Critical Ratio = Number of days until Due Date / Number of days of work Remaining

6. CR Value Meaning

CR > 1 Ahead of schedule

CR < 1 Behind schedule

CR = 1 On schedule

- Balances urgency and processing time
- Can fluctuate with time updates

Last Come First Served (LCFS)

- Process the latest arriving job first.
- Useful in dynamic environments
- Older jobs may be delayed

Longest Processing Time (LPT)

- Process jobs with the **longest processing time** first.
- Keeps machines busy longer
- Short jobs may wait unnecessarily

Summary Table

Rule	Strategy Used	Best For
FCFS	Order of arrival	Fairness, simplicity
SPT	Shortest job first	Reducing average wait time
EDD	Earliest due date	Meeting deadlines
LS	Least slack time	Urgent jobs with tight schedules
CR	Lowest critical ratio	Balanced scheduling
LCFS	Latest job first	Fast-changing environments
LPT	Longest job first	Maximizing machine utilization

Lean Operations

Question 11.

1. "Describe the concept of Lean Operations. How does it help in eliminating waste and improving efficiency?"
2. "Explain the elements of Lean Production. How do they contribute to quality and teamwork in manufacturing?"

Lean operations trace back to the Toyota Automobile Company in Japan, which revolutionized manufacturing by eliminating waste at all costs. Lean operations focus on three main types of waste



1. Waste in Time:

- **Example:** Toyota uses lean operations to minimize the time spent repairing faulty products. By implementing rigorous quality control measures, they ensure that defects are identified and addressed early in the production process, reducing downtime and keeping the production line moving smoothly.

2. Waste of Investment:

- **Example:** Companies like Dell practice just-in-time (JIT) inventory management to avoid high inventory costs. By receiving parts only when needed, Dell minimizes the capital tied up in unsold goods, ensuring that resources are used efficiently.

3. Waste of Idle Workers:

- **Example:** At McDonald's, lean operations ensure that every worker has a role to play at all times, whether it's during peak meal times or slower periods. Efficient scheduling and task rotation keep employees engaged and productive, reducing periods of inactivity.

Key Principles of Lean Operations:

- **Continuous Improvement:** Always looking for ways to make processes better.
- **Waste Elimination:** Removing any activity that does not add value to the product or service.
- **Value Stream Mapping:** Analyzing the flow of materials and information to identify and eliminate waste.

Elements of Lean Production

Lean production is built on **efficiency, teamwork, and quality**. Key elements include:

Element	Description
Value Stream View	See the organization as a flow of value from suppliers to customers
Teamwork	Organize workers into teams with clear roles
Quality Focus	Aim for perfect quality and continuous improvement
Cellular Manufacturing	Use product-based layouts instead of functional ones
Just-In-Time Mode	Produce only what is needed, when it's needed

4.10 Just-In-Time (JIT)

Objectives of JIT Manufacturing

JIT is all about **producing exactly what the customer wants, with zero waste and perfect timing**.

Goal	Description
Customer Focus	Produce what and when the customer needs
Quality Assurance	Ensure perfect quality in every unit
Speed	Minimize lead times and delays
Feature Control	Add only necessary features
Waste Elimination	Avoid waste in labour, materials, and equipment
Skill Development	Use methods that enhance worker capabilities

Overview of JIT Activities

Activity	Purpose
Inventory Reduction	Lower stock at all stages—raw, WIP, finished goods
Quality Improvement	Enhance quality inside and outside the organization
Lead Time Reduction	Cut down setup and movement times
Vendor Control	Work with fewer, high-performing suppliers
Continuous Improvement	Fix problems and seek new ways to improve

Total Preventive Maintenance	Avoid breakdowns and delays proactively
Strategic Gain	Build a competitive edge in the market

Key Takeaways

Concept	Insight
Lean Operations	Focus on waste elimination and value creation
JIT Manufacturing	Produce only what's needed, with zero excess
Shared Goal	Both aim for efficiency, quality, and customer satisfaction

QUESTIONS FROM PYP'S

Question 1.**(Dec 24 7M)**

"Production Planning and Control fulfils its various objectives by focusing on several important points/issues". With reference to this statement, append those said important points/issues. (Any Ten)

Answer:

Objectives of production planning and control

The ultimate objective of production planning and control is to contribute to the profits of the enterprise. This is accomplished by keeping the customers satisfied through the meeting of delivery schedules. Further, the specific objectives of production planning and control are to establish the routes and schedules for work that will ensure the optimum utilisation of raw materials, labourers, and machines to provide the means for ensuring the operation of the plant in accordance with these plans. Production planning and control is essentially concerned with the control of work-in-process. To control work-in-process effectively it becomes necessary to control not only the flow of material but also the utilisation of people and machines.

Production planning and control fulfils these objectives by focusing on the following points:

- i) Analysing the orders to determine the raw materials and parts that will be required for their completion,
- ii) Answering questions from customers and salesmen concerning the status of their orders,
- iii) Assisting the costing department in making cost estimates of orders,
- iv) Assisting the human resource departments in the manpower planning and assignment of men to particular jobs,
- v) Controlling the stock of finished parts and products,
- vi) Determining the necessary tools required for manufacturing,
- vii) Direction and control of the movement of materials through production process,
- viii) Initiating changes in orders as requested by customers while orders are in process,
- ix) Issuing requisitions for the purchase of necessary materials,
- x) Issuing requisitions for the purchase or manufacture of necessary tools and parts,
- xi) Keeping the up-to-date records scheduled and in process,
- xii) Maintaining stocks of materials and parts,
- xiii) Notifying sales and accounting of the acceptance of orders in terms of production feasibility,
- xiv) Preparing the route sheets and schedules showing the sequence of operation required to produce particular products,
- xv) Production of work orders to initiate production activities,
- xvi) Receiving and evaluating reports of progress on particular orders and initiating corrective action, if necessary,
- xvii) Receiving orders from customers,
- xviii) Revising plans when production activities cannot conform to original plans and when revisions in scheduled production are necessary because of rush orders.

Question 2.

In the Priority Service type of queue structure, customers in the queue are called for the service, according to the order of their arrival.

Contractors	A	B	C	D
1	39	70	37	50

2	20	27	47	63
3	25	37	58	49
4	43	48	46	50

(Each Contractor has to be assigned only one Job)

Required:

- Analyze and assign the Jobs to appropriate Contractors so as to minimize the Total Cost of the Project.
- Assess the Total Costs of the Project.

Answer:

(i) The given problem is a standard minimization problem. Subtracting the minimum element of each row from all its elements in turn, the given problem reduces to.

Again subtracting the minimum element of each column from all its elements in turn

Step 1. Row Subtraction

Job/Contractor	A	B	C	D
1	2	33	0	13
2	0	7	27	43
3	0	12	33	24
4	0	5	3	7

Step 2. Column Subtraction

Job/Contractor	A	B	C	D
1	2	28	0	6
2	0	2	27	36
3	0	7	33	17
4	0	0	3	0

Step 3. Draw the Minimum Straight lines to Cover Zeros.

Job/Contractor	A	B	C	D
1	~~2~~	28	0	~~6~~
2	0	2	27	36
3	0	7	33	17
4	~~0~~	0	3	~~0~~

Since the number of lines is less than the order of cost matrix, select the smallest element in the cost matrix not covered by the lines, subtract this element from all the uncovered elements and also added to numbers at intersection of two lines.

Job/Contractor	A	B	C	D
1	~~4~~	28	0	~~6~~
2	0	0	25	34
3	0	5	31	15
4	2	0	3	0

Step 5: Return to Step 3, cover all zeros. Since the number of lines is 4, the optimality criteria is satisfied.

Job/Contractor	A	B	C	D
1	4	28	0	6
2	0	0	25	34
3	0	5	31	15

4	2	0	3	0

Contractor	Job	Amount (Rs.) in thousand
1	C	37
2	B	27
3	A	25
4	D	50
Total		139

Hence, total minimum cost of the project will be 139000

Question 3.

Home Town Interior Decoration Ltd., uses a costly drier while painting the fire protection doors. The drier is highly volatile. It cannot be stored. In order to meet the requirement of the drier, the exact quantity is purchased every day and consumed. The Management of the Company wants to Simulate the demand of the drier. For this the Management of the Company collected data for past 100 days for the application of the drier on the number of doors and the same data are shown in the table below

Daily Demand (No. of Driers)	Number of Days
0	20
1	30
2	20
3	10
4	6
5	4
6	10

Consider the following Table of two Digit Random Numbers

Random Nos	03	23	36	93	69	43	87	51	11	08

Required:

- Using the following generated random numbers in Sequence, generate the demand of driers for next ten days.
- Assess the average demand of drier per day.

Answer:

Daily Demand (No. of Driers)	Number of Days	Probability ($p = f \div \sum f$)	Cumulative Probability	Range of Random Nos.
0	20	0.20	0.20	0-19
1	30	0.30	0.50	20-49
2	20	0.20	0.70	50-69
3	10	0.10	0.80	70-79
4	6	0.06	0.86	80-85
5	4	0.04	0.90	86-89
6	10	0.10	1.00	90-99
	$\sum f = 100$			

Simulated Data

Day	Random No.	Daily Demand
1	03	0



2	23	1
3	36	1
4	93	6
5	69	2
6	43	1
7	87	5
8	51	2
9	11	0
10	08	0
	Total	18

Average Demand of Drier per day = $18 / 10 = 1.8$ Driers

Question 4.

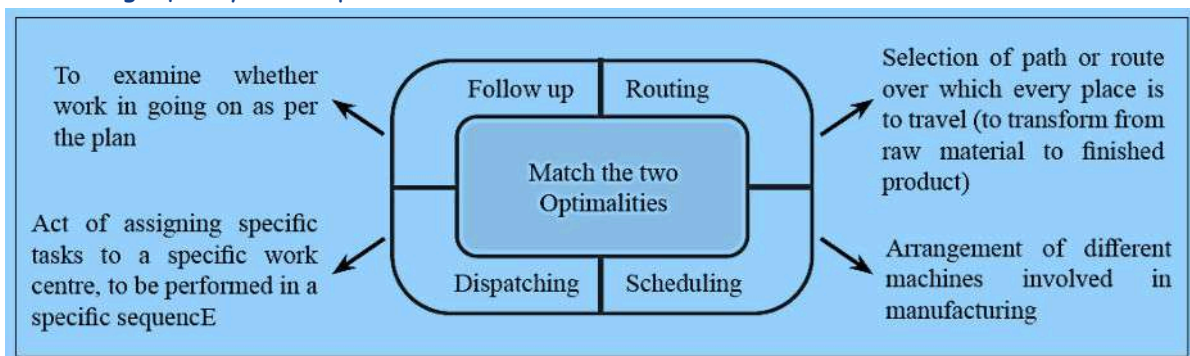
(Jun 24 7M)

"Production Control involves the various functions". In accordance with this align these said functions

Answer:

Production control involves the following functions:

- Planning the production operations in detail,
- Routing, i.e., laying down the path for the work to follow and the order in which the various operations will be carried out,
- Scheduling, i.e., establishing the quantity of work to be done, and fixing the time table for performing the operations,
- Dispatching, i.e., issuing the necessary orders, and taking necessary steps to ensure that the time targets set in the schedules are effectively achieved
- Follow-up, taking necessary steps to check up whether work proceeds according to predetermined plans and how far there are variances from the standards set earlier,
- Inspection, i.e., conducting occasional check-ups of the products manufactured or assembled to ensure high quality of the production.



Techniques of Production Control

Question 5.

(Jun 24 7M)

In a Book Sales Emporium of PRANTIK (B) Ltd., four Salesmen A, B, C and D are available in four Counters P, Q, R and S. Each Salesman can handle any counter. Their Services (in hours) of each counter, when manned by each Salesman is given below :

	Counter			
Salesman	P	Q	R	S
A	30	46	34	22



B	11	20	11	5
C	28	43	28	18
D	14	23	17	8

Required:

- 1) Analyze and Assign the Salesmen to appropriate counters so as to minimize the service time.
- 2) Assess the total service times (in hours).

Answer:

Counter						
Salesman	P	Q	R	S	Row Min	
A	30	46	34	22	22	22
B	11	20	11	5	5	5
C	28	43	28	18	18	18
D	14	23	17	8	8	8

Row Operation Matrix

Salesman	P	Q	R	S
A	8	24	12	0
B	6	15	6	0
C	10	25	10	0
D	6	15	9	0
	6	15	9	0

Counter				
Salesman	P	Q	R	S
	2	0	6	0
	0	0	0	0
	4	10	4	0
	0	0	3	0

No. of zeros with square 0 = 4 = order of the matrix (s). So the solution is non-optimal

The optimal assignment is

Salesmen	Counter	Service time (Hour)
A	P	30
B	R	11
C	S	18
D	Q	23
Total		82

Question 6.

(Jun 24 7M)

A production line of ZFORD (MI Ltd., turns out about trucks per day; fluctuations occur for many reasons. The production can be described by a probability distribution as follows:

Production Per Day	Probability	Production Per Day	Probability
45	0.03	51	0.15
46	0.05	52	0.10
47	0.07	53	0.07
48	0.10	54	0.05

49	0.15	55	0.03
50	0.20		

Finished trucks transported by a Train at the end of the day. The train capacity is only 51.

[Given : Random number: 37, 35, 63, 25, 50, 71, 95, 16, 55 and 53]

Required:

- (1) Using the Random numbers stated Supra. Simulate the productions and waiting of trucks in the factory for the first 10 days.
- (2) Evaluate the average number of trucks waiting in the Factory.
- (3) Assess what will be the average number of empty spaces on the train.

Answer:

Production Per day	Probability	Cumulative Probability	Random Range
45	0.03	0.03	00-02
46	0.05	0.08	03-07
47	0.07	0.15	08-14
48	0.10	0.25	15-24
49	0.15	0.40	25-39
50	0.20	0.60	40-59
51	0.15	0.75	60-74
52	0.10	0.85	75-84
53	0.07	0.92	85-91
54	0.05	0.97	92-96
55	0.03	1.00	97-99

Day	Random No.	Production	No. of Trucks waiting to be Shipped	No. of empty space in Train
1	37	49	-	2
2	35	49	-	2
3	63	51	-	-
4	25	49	-	2
5	50	50	-	1
6	71	51	-	-
7	95	54	3	-
8	16	48	-	3
9	55	50	-	1
10	53	50	-	1
Total			3	12

Average no. of trucks waiting in the factory = $3/10 = 0.30$ per day

Average no. of empty space on the boat = $12/10 = 1.2$ per day

Question 7.

(Dec 23 7M)

Summarize the Basic types of Production Control.

Answer:

Basic types of production control:

Production control can be of six types:

i) Block control

This type of control is most prominent in textiles and book and magazine printing. In these industries it is necessary to keep things separated and this is the fundamental reason why industries resort to block control.

ii) Flow control

This type of control is commonly applied in industries like chemicals, petroleum, glass, and some areas of food manufacturing and processing. Once the production system is thoroughly designed, the production planning and control department controls the rate of flow of work into the system and checks it as it comes out of the system. But, under this method, routing and scheduling are done when the plant is laid out. That is to say, the production line which is established is well balanced and sequenced before production operations begin; this type of control is more prevalent in continuous production systems.

iii) Load control

Load control is typically found wherever a particular bottleneck machine exists in the process of manufacturing.

iv) Order control

The most, common type of production control is called order control. This type of control is commonly employed in companies with intermittent production systems, the so-called job-lot shops. Under this method, orders come into the shop for different quantities for different products. Therefore, production planning and control must be based, on the individual orders.

v) Special project control

Special production control is necessary in certain projects like the construction of bridges, office buildings, schools, colleges, universities, hospitals and any other construction industries. Under this type of control, instead of having sets of elaborate forms for tooling and scheduling, a man or a group of men keeps in close contact with the work.

vi) Batch control

Batch control is another important, type of production control which is frequently found in the food processing industries. Thus, production control in batch-system of control operates with a set of predefined quantities or batches of raw materials processed together as a group. The processing steps are designed to handle a specific batch size, allowing for efficient and controlled production of food products such as beverages, sauces, and other items that are produced in distinct batches. This method is particularly suitable for industries where variations in raw materials or processing conditions can be managed more effectively in discrete, manageable batches.

Question 8.

(Dec 23 7M)

In a job shop operation of ZINT Ltd., five jobs may be performed on any four machines. The hours are required for each job on each machine are presented in the following table.

Job	Machine 1	Machine 2	Machine 3	Machine 4
A	6	2	5	2
B	2	5	8	7
C	7	8	6	9
D	6	2	3	4
E	9	3	8	9



The plant foreman would like to assign the jobs so that the total time is minimised.

Required: Develop the Optimal assignment of jobs to Machines and Assess the Corresponding Total Time (in hours) and also identify the job which will be left unassigned.

Answer:

Machine					
Job	1	2	3	4	Dummy
A	6	2	5	2	0
B	2	5	8	7	0
C	7	8	6	9	0
D	6	2	3	4	0
E	9	3	8	9	0
	2	2	3	2	0

Dummy column is introduced to make the no. of columns = no. of rows, as this is the basic requirement for assignment with the Hungarian method.

Column Operation Matrix

Machine					
Job	1	2	3	4	Dummy
A	4	0	2	0	0
B	0	3	5	5	0
C	5	6	3	7	0
D	4	0	0	2	0
E	1	1	5	7	0

Column Operation Matrix

No. of zeros with square = 04 $\neq$ order of the matrix (s). So the solution is non-optimal.

Improved Matrix

Machine					
Job	1	2	3	4	Dummy
A	4	0	2	0	1
B	0	3	5	5	1
C	4	5	2	6	0
D	4	0	0	2	1
e	6	0	4	6	0

No. of zeros with square [OJ = 5 = order of the matrix (s). So the solution is optimal. So the optimal assignments are as follows

So the optimal assignments are as follows:

Jobs	Machine	Hours
A	4	2
B	1	2
C	Dummy	0
D	3	3
E	2	3
Total time (in hours) =		10 hours

Job left unassigned= Job C



Question 9.

(Dec 23 7M)

RAGON (P) & Co. has a single machinist in a repair shop. He works eight hours a day and on average four machines break each day. It takes on the average one hour to repair a machine. Simple queue conditions exist.

Required:

- Identify the expected number of machines on the repair shop.
- Determine the expected number of machines in the shop on which the machinist has not started to work.
- Assess the average down-time (waiting for repairs or undergoing repairs) per machine?
- The average time a machine waits for service would be how much?

Answer:

The arrival rate is $\lambda = 4$ machines/day = $4/8 = 1/2$ machines/hr

The service rate, $\mu = 1$ machine/hour

- Expected number of machines in the repair shop:

$$L_s = \frac{\lambda}{\mu} = \frac{1/2}{1 - 1/2} = \frac{1/2}{(2-1)/2} = \frac{1/2}{1/2} = 1 \text{ Machine}$$

- Expected number of machines in the shop on which machinist has not started to work

$$L_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{1/2}{1 - 1/2} = \frac{1/2}{(2-1)/2} = \frac{1/2}{1/2} = 1 \text{ Machine}$$

- Average down-time (waiting for repairs or undergoing repairs) per machine.

$$W_s = L_s / \lambda$$

$$= \frac{1}{1/2} = \frac{1}{0.5} = 2 \text{ Hours}$$

- Average time a machine waits for service would be

$$W_q = \frac{L_q}{\lambda} = \frac{1}{1/2} = \frac{1}{0.5} = 2 \text{ Hours}$$

Question 10.

(Dec 23 6M)

The Time remaining (number of days until due date) and the work remaining (number of days still required to finish the work) for 6 Jobs of ROBIN Ltd., which were assigned the Jobs P to T and Z as they are arrived to the shop, are shown below:

Jobs	Number of days until due date	Number of days of work remaining
P	8	4
Q	5	8
R	4	3
S	9	6
T	7	5
Z	10	10

Required:

Sequence the Jobs according to priority established by

- Least Slack (LS) Rule
- Longest Processing Time (LPT) Rule
- Critical Ratio Rule

Answer:

(i) Least Slack Rule also called Minimum Slack Rule

Calculation of Slack;

Slack (Number of days until due date) - (Numbers of days of work remaining)

Jobs	No. of days until due date	No. of days of work remaining	Slack (Days)
P	8	4	4
Q	5	8	-3
R	4	3	1
S	9	6	3
T	7	5	2
Z	10	10	0

Job	Q	Z	R	T	S	P
Slack	-3	0	1	2	3	4

(ii) Longest Processing Time :

As per this rule jobs are sequenced in descending order of magnitude of their respective processing times.

Sequence

Job	Z	Q	S	T	P	R
Processing Time (Days)	10	8	6	5	4	3

(iii) Critical Ratio Rule:

Critical Ratio = Available time till due date/operation time still needed to complete the job

Critical Ratio for job P = $8/4 = 2$

Critical Ratio for job Q = $5/8 = 0.625$

Critical Ratio for job R = $4/3 = 1.333$

Critical Ratio for job S = $9/6 = 1.5$

Critical Ratio for job T : $7/5 = 1.4$

Critical Ratio for job z = $10/10 = 1$

Job with the least critical ratio is given the first priority and so on.

Sequence	Q	Z	R	T	S	P
Critical Ratio	0.625	1	1.333	1.4	1.5	2

Question 11.

(Dec 23 8M)

A marketing manager of AOVN Ltd, has four salesmen and four sales districts. Considering the capabilities of the salesmen and the nature of districts. Marketing manager estimates that sales per month (in thousand rupees) for each salesman in each district would be as follows:

SALESMAN	A	B	C	D
P	40	33	26	19
Q	28	23	18	13
R	28	23	18	13
S	22	18	14	10

Required:

- Suggest a suitable allocation of salesmen with the districts so that total sales will be maximum..
- Assess the total sales (in thousand rupees) pertaining thereto

Answer:

This is a problem of Maximisation. To solve it using Assignment technique it has to be converted to a Minimisation problem by forming a Relative loss matrix.

Relative Loss Matrix

Salesman	A	B	C	D	
P	0	7	14	21	0
Q	12	17	22	27	12
R	12	17	22	27	12
S	18	22	26	30	18

The matrix is formed by subtracting all the elements of the given matrix from the highest element (40) of it.

Row Operation Matrix

Salesman	A	B	C	D
P	0	7	14	21
Q	0	5	10	15
R	0	5	10	15
S	0	4	8	12

Column Operation Matrix

DISTRICT				
Salesman	A	B	C	D
P	0	3	6	9
Q	0	1	2	3
R	0	1	2	3
S	0	0	0	0

No. of zeros with square $[O] = 2 \neq$ order of the matrix (4). So the solution is non optimal.

Improved Matrix

DISTRICT				
Salesman	A	B	C	D
P	0	2	5	8
Q	0	0	1	2
R	0	0	1	2
S	1	0	0	0

No. of zeros with square $[O] = 3 \neq$ order of the matrix (4). So the solution is non optimal

So the optimal assignments are as follows:

Sales	District	Sale (in thousand ₹)
P	A	40
Q	B	23
R	C	18
S	D	10
Maximum Total Sales =		91(in thousand ₹)

Question 12.

(Dec 23 8M)

Observations of past data show the following patterns in respect of inter-arrival duration and service duration in a single channel queuing system:

Arrival of Customers		Services	
Inter-Arrival Time (Minutes)	Probability	Service Time (Minutes)	Probability
2	0.20	4	0.25
4	0.24	6	0.34
6	0.28	8	0.26
8	0.18	10	0.15
10	0.10	-	-

The random numbers are given to be used for the simulation of arrival and service patterns.

Arrival	74	22	90	05	42
Service	40	18	71	92	64

Required:

Simulate the queue for the first 5 arrives and assess the following:

- Average waiting time of a customer.
- Average idle time in the queue.

Answer:

Mins	Probability	Cumulative Probability	Range	Mins	Probability	Cumulative Probability	Range
2	0.20	0.20	0-19	4	0.25	0.25	0-24
4	0.24	0.44	20-43	6	0.34	0.59	25-58
6	0.28	0.72	44-71	8	0.26	0.85	59-84
8	0.18	0.90	72-89	10	0.15	1.00	85-99
10	0.10	1.00	90-99			0.25	

SL. No.	Random No. for inter arrival time	Inter arrival time (Mins)	Entry time in queue as per clock	Service start time as per clock	Random No. for service time	Service time (Mins)	Service end time as per clock	Waiting time of customer (Mins)	Idle time (Mins)
1	74	8	8:08	8:08	40	10	8:14	-	8
2	22	4	8:12	8:14	8	10	8:18	2	-
3	90	10	8:22	8:22	71	10	8:30	4	-
4	05	2	8:24	8:30	92	10	8:40	6	-
5	42	04	8:28	8:40	64	8	8:48	12	-
Total								20	12

Assuming the clock starts at 8:00 A.M.

Avg. time spent by customer waiting in queue= $20/5 = 4$ Minutes

Avg. idle time in the queue= $12/5 = 2.4$ Minutes

Question 13.

(Jun 23 8M)

Below table shows the time remaining (number of days until due date) and the work remaining (number of days still required to finish the work) for 5 jobs which were assigned the letters A to E as they arrived at the shop.

Job	Number of days until due date	Supply (Tonnes)
A	6	3

B	4	8
C	2	5
D	8	6
E	7	2

Required:

Sequence the jobs according to priority established by

- (i) Early Due Date (EDD) Rule
- (ii) Least Slack (LS) Rule
- (iii) Longest Processing Time (LPT) Rule
- (iv) Critical Ratio Rule

Answer:

- Earliest Due Date (EDD) Job First : C - B - A - E - D: 2 - 4 - 6 - 7 - 8
- Least Slack Rule

Job	No. of days until due date	No. of days work remaining	Slack days
A	6	3	3
B	4	8	-4
C	2	5	-3
D	8	6	2
E	7	2	5

Slack Days = No. of days until due date - No. of days work remaining.

Least Slack Rule: B-C-D-A-E: (-4)-(-3)-2-3-5

- Longest Processing Time (LPT) : B-D-C-A-E : 8-6-5-3-2
- Critical Ratio Rule

Job	No. of days until due date	No. of days work remaining	Critical Ratio
A	6	3	6/3=2
B	4	8	4/8 = 0.5
C	2	5	2/5 0.4
D	8	6	8/6= 1.333
E	7	2	7/2=3.535

Critical Ratio Rule: C-B-D-A-E

Question 14.

(Jun23 7M)

A factory of SPON LTD. manufacturers 3 products which are processed through 3 different production stages. The time required to manufacture one unit of each of the three products and the daily capacity of the stages are given in the following table:

Stage Capacity Table:

State	Time/Unit in Minutes			Stage Capacity (Minutes)
	Product 1	Product 2	Product 3	Capacity
1	1	2	1	430
2	3	-	2	460
3	1	4	-	420
Profit/Unit	₹3	₹2	₹5	

Required:

Develop a linear programming model to determine how many products to be manufactured to maximize profit.

Answer:

Let x be the no. of units of Product 1

Let y be the no. of units of Product 2

Let z be the no. of units of Product 3

Objective Function: $\text{Max } Z = 3x + 2y + 5z$

Subject to Constraints:

$x + 2y + z \leq 430$ (Constraint on Stage capacity (in mins) of State 1)

$3x + 2z \leq 460$ (Constraint on Stage capacity (in mins) of State 2)

$x + 4y \leq 420$ (Constraint on Stage capacity (in mins) of State 3)

And $x, y, z \geq 0$ (Non-negativity constraint)

Question 15.

(Jun 23 6M)

TANEESA, a car rental Agency has collected the following parameters on the demand for five-seater vehicles over the past 50 days.

Daily Demand	5	6	7	8	10
No. of Days	4	10	16	14	6

The agency has only 7 cars currently.

[Given: Random numbers: 15, 48, 71, 56, 90]

Required:

(1) Using the Random numbers stated supra, develop 5 days of demand for the car rental agency.

(2) Calculate the average number of cars rented per day for the 5 days.

(3) Assess how many rentals will be lost over the 5 days.

Answer:

Random No. Range Table for Demand

Daily Demand	Frequency (f)	Probability ($p = f / \Sigma f$)	Cumulative Probability	Range of Random Nos.
5	4	0.08	0.08	00-07
6	10	0.20	0.28	08-27
7	16	0.32	0.60	28-59
8	14	0.28	0.88	60-87
10	6	0.12	1.00	88-99
	$\Sigma f = 50$	1.00		

Simulated Values for 5 Days

Days	Random Nos.	Demand	Cars Rented	Lost Rentals
1	15	6	6	-
2	48	7	7	-
3	71	8	7	1
4	56	7	7	-
5	90	10	7	3
Total		38	34	4

Average Daily Demand = $34/5 = 6.8$



Rentals Lost over 5 days = 4

Question 16.

(Jun 23 6M)

MANU, what department store has one cashier. During the peak hours, customers arrive at a rate of 24 per hour. The average number of customers that can be handled by the cashier is 30 per hour. Assume the conditions for use of a single channel queueing model.

Required:

1. What is the average number of customers in the system including the customers being served?
2. What is the average waiting time for the customers who waits?
3. Find the probability of finding at least one customer in the store.

Answer:

Arrival Rate : $A = 24$ customer/hr

Service Rate : $\mu = 30$ customers/hr

- Average number of customers in the system (including the customers being served)

$$L_s = \lambda / (\mu - \lambda) = 24 / (30 - 24) = 4$$

- Average waiting time for the customers who waits:

$$W_q = L_q / \lambda = 1 / \lambda \times \lambda^2 / (\mu(\mu - \lambda)) = \lambda / (\mu(\mu - \lambda)) = 24 / (30(30 - 24)) = 0.1333 \text{ hours or 8 mins}$$

- Probability of finding at least 1 customer in the system.

$$\text{Probability zero customers in system: } P_0 = 1 - \lambda / \mu = 1 - 24 / 30 = 0.2$$

$$\text{Probability of finding at least one customer in system } (P_n > P_0) = 1 - P_0 = 1 - 0.2 = 0.8$$

Question 17.

(Jun 23 7M)

RANG LTD., a manufacturing company, dealing with a special type of product has three parts F, G and H located throughout the country. Production capacities of these plants are respectively 40, 60 and 20 tonnes. Each day the company must furnish four of its retail outlets of A, B, C and D with at least 16, 16, 40 and 48 tonnes of the product. The transportation cost per tonne (in Rs. '000) between various types of plants and retail outlets are given below:

From Plants	A	B	C	D	Supply (Tonnes)
F	3	5	7	6	40
G	2	5	8	2	60
H	3	6	9	2	20
Demand (Tonnes)	16	16	40	48	

Required:

- (i) Find the basic feasible solution for the problem of transportation using Vogel's Approximation Method (VAM).
- (ii) Prepare transportation schedule with its associated cost and total cost of transportation

Answer:

	A	B	C	D	Supply (Tonnes)		Row Penalty		
F	~~3~~ 16	~~5~~	~~7~~ 24	~~6~~	40 24	(2)	1	1	2
G	~~2~~	~~5~~ 16	~~8~~ 16	~~2~~ 28	60 32 16	0	3	3	(3)
H	~~3~~	~~6~~	~~9~~	~~2~~ 20	20	1	(4)	-	-
Demand (Tonnes)	16	16	40 16	48 28	120				
	1	0	1	0					
Column Penalty	-	0	1	0					
	-	0	1	(4)					
	-	0	1	-					

$m+n-1 = 3 + 4 - 1 = 6$ no. of allotment = 6

As, $m+n-1$ = no. of allotment, therefore this is the basic feasible solution

Transportation Schedule	
Plants to Retail Outlet	Associated Cost/tonne (₹'000)
F to A	$16 \times 3 = 48$
F to C	$24 \times 7 = 168$
G to B	$16 \times 5 = 80$
G to C	$16 \times 8 = 128$
G to D	$28 \times 2 = 56$
H to D	$20 \times 2 = 40$
	512

Question 18.

(Dec 22 9M)

The following table shows the time remaining (number of days until the due date) and the work remaining (number of days still required to finish the work) for 5 jobs of ZBA Ltd. which were assigned the letters A to E as they arrived at the shop

Job	Number of days until due date	Number of days of work remaining
A	12	13
B	7	9
C	2	5
D	8	4
E	4	1

Required:

Sequence the jobs according to priority rules established by (i) First cum first served (FCFS) (ii) Early due date job first (EDD) (ii) Least slack (LS) (iv) Shortest processing time job first (SPT) and (v) Longest processing time job first (LPT).

Answer:

- i) FCFS (First come first served): Since the jobs are assigned letters A to E as they arrived to the shop, the sequence according to FCFS priority rule is: A, B, C, D, E.
- ii) EDD (Early due date job first) rule: Taking into account the number of days until due date, the sequence of jobs as per EDD rules is:

Jobs	C	E	B	D	A
No. of days until due date	2	4	7	8	12

- iii) LS (Least slack) rule also called as Minimum slack rule.

Calculation of slack:

Slack = (Number of days until due date) - (Number of days work remaining)

Jobs	Number of days until due date	Number of days of work remaining	Slack (Days)
A	12	13	12 - 13 = -1
B	7	9	7 - 9 = -2
C	2	5	2 - 5 = -3
D	8	4	8 - 4 = 4
E	4	1	4 - 1 = 3

Sequence is thus :

Jobs	C	B	A	E	D
No. of days until due	-3	-2	-1	3	4
Date					

- iv) SPT (Shortest Processing Time job first) also referred as SOT (Shortest Operation time job First) rule or MINPRT (Minimum Processing time job first) rule. Sequence is thus

Jobs	E	D	C	B	A
Processing time (days)	1	4	5	9	13

- v) LPT (Longest Processing time job first) also referred to as LOT (Longest Operation time job first) rule. Sequence is thus :

Jobs	A	B	C	D	E
Processing time (days)	13	9	5	4	1

Question 19.

(Dec 22 8M)

MABUN Ltd. a company producing industrial adhesives has four sales representatives who are to be assigned to four outlets in metro cities. The monthly sales (F in lakh) increase estimated for each salesman for different sales territories is shown in the following table:

Salesman	City A	City B	City C	City D
I	47	40	33	26
II	35	30	25	20
III	35	30	25	20
IV	29	25	21	17

Required:

- i) Find the optimum assignment of salesmen to outlets (cities).
- ii) Find the total maximum sales (Rs. in lakh) increase per month

Answer:

Relative Loss Matrix

City / Salesman	A	B	C	D
I	0	7	14	21
II	12	17	22	27
III	12	17	22	27
IV	18	22	26	30

As this is a problem of Maximization, the same is converted to one of Minimization by firming a Relative Loss Matrix where all the elements of the given matrix are subtracted from the highest element of the matrix (which is 47 in this case).

Matrix after Row Operation

City / Salesman	A	B	C	D
I	0	7	14	21
II	0	5	10	15
III	0	5	10	15
IV	0	4	8	12

Matrix after Column Operation

City / Salesman	A	B	C	D
I	0	3	6	9
II	0	1	2	3
III	0	1	2	3
IV	0	0	0	0

Note: The minimum number of horizontal and vertical straight lines required to cover all zeros is 2. The order of the matrix is 4, so the solution is non-optimal. Let me know if you'd like further modifications!

Improved Matrix (Non Optimal)

City / Salesman	A	B	C	D
I	0	2	5	8
II	0	0	1	2
III	0	0	1	2
IV	1	0	0	0

Note: The minimum number of horizontal and vertical straight lines required to cover all the zeros is 3. The order of the matrix is 4, so the solution is non-optimal.

Further Improved Matrix [Optimal Solution (i)]

City / Salesman	A	B	C	D
I	0	2	4	7
II	0	0	0	1
III	0	0	0	1
IV	0	1	0	0

Note: The minimum number of horizontal and vertical straight lines required to cover all the zeros is 4. The order of the matrix is 4, so the solution is optimal. Let me know if you'd like any further changes!

Further Improved Matrix [Optimal Solution (i)]



City / Salesman	A	B	C	D
I	0	2	4	7
II	~~0~~	~~0~~	0	1
III	~~0~~	0	~~0~~	1
IV	2	1	~~0~~	0

(ii)

(i) and (ii) (Rs. In Lakh)

Assignment as per Solution(i)			Assignment as per Solution (ii)		
Salesman	City	Sales	Salesman	City	Sales
I	A	47	I	A	47
II	B	30	II	B	30
II	C	25	II	C	25
IV	D	17	IV	D	17
Total		119	Total		119

Question 20.

(Dec 22 8M)

The counter of a Ration shop experiences the arrival of 25 customers during peak working hours. Service time will have Poisson Distribution. Experience suggests that mean service time should average about two minutes per customer.

Determine each of the following:

- (i) System utilization,
- (ii) Percentage of time the server (agent) will be idle,
- (iii) The expected number of customers waiting to be served,
- (iv) The average time customers will spend in the system.

Answer:

- i) System Utilization = 0.8333
- ii) Percentage of time the Server (agent) will be idle : = 0.1667, or 16.67 %
- iii) Expected no. of customers waiting to be served. = 4.17customers
- iv) Average time customers will spend in the system = 0.200 hours= 12 minutes

MODULE 5. PRODUCTIVITY MANAGEMENT AND QUALITY MANAGEMENT

Questions For Classroom Discussion

Question 1

(Illustration 1)

In a particular plant there are 10 workers manufacturing a single product and the output per month consisting of 25 days of that particular product is 200. How much is the monthly productivity? (Monthly productivity per worker)

Note:

After this question, you should be able to complete Question No. 11 on your own. This question appeared in a previous online exam and was also tested in December 2024 for two marks.

Question 2

(Illustration 11) Home Work

A cement factory in Madhya Pradesh works 7 days a week in 3 shifts per days having maintenance in the first shift of around 2 hours. It has roughly 100 workers which produces only pozzolanic properties cement better known as PPC.

The output per month is around 2500 tonnes of PPC. Find the productivity per worker

Question 3

(Illustration 2) Question also Appeared In A Previous Online Exam

There are two industries A and B manufacturing hose couplings. The standard time per piece is 15 minutes.

The output of two small scale industries is 30 and 20 units respectively per shift of 8 hours.

Find the productivity of each per shift of 8 hours?

What is the expected production of each per week consisting of 6 days?

After this question, Students should be able to complete Question No. 12 on your own.

Question 4

(Illustration 12) Home Work

Compare the productivity of two plant of tobacco company situated in two different state Y and Z in an 8-hour shift. The standard time in manufacture a tobacco packet is 10 min. The output is 40 and 55 of two different plants in a shift.

Find also the expected productivity of both plants in a week.

Question 5

Illustration 3

The following data is available for a machine in a manufacturing unit:

Hours Worked	8
Working Days Per Month	25
Number of Operator	1
Standard Minutes Per Unit	
Machine Time	22
Operator Time	8
Total Time	30

- Q.1 If plant is operated at 75% efficiency, and the operator is working at 100% efficiency, what is the output per month?
- Q.2 If machine productivity is increased by 10% over the existing level, what will be the output per month?
- Q.3 If operator efficiency is reduced by 20% over the existing level, what will be the output per month?

Note:

Question Number 3 has been tested in the main exam multiple times, with variations in the figures. It has been assigned 9 marks and 6 marks in different instances. Additionally, there is a mistake in the institute material solution to Question C.

Question 6

(Illustration 13)

For the given data of manufacturing unit which produces spare parts of HEMM the operators time, machine time and total time are 10, 28 and 38 minutes respectively. If there are one operator and working hour per day is 8 hour and considering 22 working days in a month. Find

- (a) If plant is working at 65% efficiency, what is the expected output per month?
- (b) If plant productivity is increased by 20% over the existing level, what will be the output per month?
- (c) If operator efficiency is reduced by 30% due to injury over the existing level, what will be the output per month?

Please note that there is an error in the solution to Question C in the institute study material.

Question 7

(Illustration 4)

The following data is available for a manufacturing unit :

Number of operators =15

Daily working hours = 8

No. of days per month =25

Standard production per month =300 units

Standard Labour hours per unit = 8

The following information was obtained for November 2015:

Man days lost due to absenteeism = 30

Unit produced = 240

Idle Time = 276-man hours

Find the following

- Q.1 Percent absenteeism
- Q.2 Efficiency of utilization of labour
- Q.3 Productive efficiency of labour
- Q.4 Overall productivity of labour in terms of units produced per man per month.

After the fourth question, students can attempt Question 14. This question was tested in a previous year's online exam.

Question 8

(Illustration 14) Home Work

Following are the data related to call centre Firm which gives tech and non-tech support to large IT companies. It has 20 executives to address the queries which has 8 hour a shift having on an average 24 working days in month. On an average the company is able to address around 290 calls in a month.

Additional data for the current month is obtained

- (a) No of call logged for the month = 250
- (b) Idle time = 275-man hours
- (c) Man days lost (absenteeism) = 28.

Question 9

(illustration 5)

An incentive scheme allows proportionate production bonus beyond 100% performance level. Calculate the amount of

Q.1 Incentive bonus and

Q.2 Total payment received by an operator on a particular day during which the following particulars apply:

Additional Information

- ✓ Operation - Assembling pocket transistor radio set
- ✓ Work Content - 30 Standard minutes per assembled set
- ✓ Attended Time : 8 Hours
- ✓ Time spent on unmeasured work : 2 Hours
- ✓ Numbers of sets assembled during the day : 15
- ✓ Wage rate : 4 per hour

Q.3 What is the net labour productivity achieved by the operator during the day?

After this question, students can attempt Question No. 15.

Question 10

(Illustration 15) Home Work

Compute the productivity per machine hour with the following data.

Also draw your interpretation.

Month	Number of Machine Employed	Working Hours	Production Units
January	400	220	99,000
February	550	180	100,000
March	580	220	125,000

Question 11

(Illustration 6)

Find the productivity of IT firm in terms of business achieved for the following data and comment

Quarter	No of Employees	Working Hours	Business Achieved
Q1	1,600	800	1,000,000
Q2	1,500	750	1,024,000
Q3	1,700	775	1,300,000
Q4	2,000	900	1,200,000

Question 12

(Illustration 7)

Calculate the standard production per shift of 8 hours duration, with the following data:

Observed time per unit = 5 minutes,

Rating Factor = 120%,

Total allowances = 30% of normal time.

Question 13

(Illustration 16)

Find the standard production for 8 hour shift. If allowance = 25% of normal time, Observer time per unit is 7 min and the rating factor is 110%.

Question 14

(Illustration 8)

Study in the packaging department of a soft drinks manufacturing unit revealed the following facts for a worker Basant Rao Patil.

Activity Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Performance Rating
Get Empty Cartoon (A)	0.15 minutes	0.25 minutes	****	0.17 minutes	90%
Place 30 Bottles in the Cartoon (B)	1.56 minutes	****	1.80 minutes	1.75 minutes	105%
Close the Cartton and Set Aside (C)	0.20 Minutes	****	0.10 minutes	0.15 minutes	95%
Smoking (D)	****	0.50 minutes	****	****	****

Calculate the standard production by Basant Rao in a shift of 8 hours when the units standard rules allow 10% as Allowance Factor.

Question 15

(Illustration 9)

A department works on 8 hours shift, 288 days a year and has the usage data of a machine, as given below:

Product	Annual Demand	Processing Time
A	325	5
B	450	4
C	550	6

Calculate

- Q1) Processing time needed in hours to produce products A, B and C
 Q2) Annual production capacity of one machine in standard hours, and
 Q3) Number of machines required.

Question 16

(Illustration 17)

Find the standard production for 8 hr shift. If allowance = 25% of normal time, Observer time per unit is 7 min and the rating factor is 110%.

Answer:

Normal time per unit = Observed time / unit $\times$ Rating factor = $7 \times (110/100) = 7.7$ minutes

Now, Allowances = 25% of normal time = $(25 \times 7.7)/100 = 1.925$ minutes.

So, Standard time/unit = Normal time/unit + Allowances = $7.7 + 1.925 = 9.625$ minutes / unit

Hence, Standard production in shift of 8 hours = $(8 \times 60)/9.625 = 49.89$ units (50 Units approx.)

Question 17

(Illustration 10)

Following results are recorded in a study of work sampling carried for 100 hours in a Machine Shop.

- ✓ Total number of observations recorded = 2500
 - ✓ Number of observations in which no working activity is noticed = 400
 - ✓ Ratio of Manual to Machine elements = 2:1
 - ✓ Average Rating Factor = 115%
 - ✓ Number of articles produced during the study period = 6000
 - ✓ As per the policy of the company,
 - ✓ Rest and personal allowances are taken as 12% of Normal Time.
- 1) Calculate Standard Time to produce an article?
Given that the shop produces 42000 articles per month of 25 working days by 5 workers working for a shift of 8 hours per day. Consider absenteeism to be 7%.
 - 2) Compute Efficiency of utilization of Labour and
 - 3) Productive Efficiency of Labour?

Question 18**(Illustration 18)**

Below data are collected related to work study for 150 hrs on a floor shop employing 7 labours having a shift of 8 hrs in a day.

- ✓ Number of observations documented in total = 3000
 - ✓ Number of observations in which no working activity is observed = 500
 - ✓ Manual to machine ratio = 3:2
 - ✓ Average Rating factor = 120%
 - ✓ Number of product produced during the period of study = 7000
 - ✓ Company has its own policy regarding personal allowance which is pegged at 11% of normal standard time to produce a product.
 - ✓ The floor shop produces 49000 products per month for 24 working days, it has an absenteeism of around 6%.
- 1) Calculate efficiency of utilization of Labour and
 - 2) Productive Efficiency of Labour.

5.1 Measurement Techniques of Productivity Index

Illustrations From Study Material

Illustration 1:

In a particular plant there are 10 workers manufacturing a single product and the output per month consisting of 25 days of that particular product is 200. How much is the monthly productivity?

Answer:

Monthly productivity per worker = $200 / 10 = 20$ units

Illustration 2:

There are two industries A and B manufacturing hose couplings. The standard time per piece is 15 minutes. The output of two small scale industries is 30 and 20 respectively per shift of 8 hours. Find the productivity of each per shift of 8 hours. What is the expected production of each per week consisting of 6 days?

Answer:

$$\text{Productivity} = \frac{\text{Actual production}}{\text{Standard production}}$$

$$\text{Standard production of hose couplings per shift} = \frac{8 \times 60}{15} = 32 \text{ pcs.}$$

$$\text{Productivity of industry A} = \frac{30}{32} = \frac{15}{16} \text{ and productivity of industry B} = \frac{20}{32} = \frac{5}{8}$$

If the productivity is expressed in percentage, the same for A is $\frac{15}{16} \times 100 = 93.75\%$

and productivity of industry B is $\frac{5}{8} \times 100 = 62.5\%$

Production per week of industry A = $30 \times 6 = 180$ nos. (Assuming the industry to work for one shift per day)

Production per week of industry B = $20 \times 6 = 120$ nos. (Assuming the industry to work for one shift per day)

Illustration 3:

The following data is available for a machine in a manufacturing unit:

Hours worked per day	8
Working days per month	25
Number of operators	1
Standard minutes per unit of production	
Machine time	22
Operator time	8
Total time per unit	30

- If plant is operated at 75% efficiency, and the operator is working at 100% efficiency, what is the output per month?
- If machine productivity is increased by 10% over the existing level, what will be the output per month?
- If operator efficiency is reduced by 20% over the existing level, what will be the output per month?

Answer:

(a) Hours worked per day = 8

Working days per month = 25

Hours worked per month = $25 \times 8 = 200$ hrs.

Machine time = 22 minutes

Operator time = 8 minutes

Total time per unit = 30 minutes = $\frac{1}{2}$ hr.No. of units that can be produced/month/operator = $\frac{200}{1/2} = 400$

As the no. of operator is 1, possible monthly production = 400 units. As the plant operates at 75% efficiency.

Monthly production = $400 \times \frac{75}{100} = 300$ units.

(b) If machine productivity is increased by 10% i.e. Machine time = $22 \times \frac{100}{(100+10)}$
= 20 minutes.

Then, total time = $20 + 8 = 28$ minutesMonthly production = $\frac{400 \times 30}{28} \times \frac{75}{100} = 321$ Units

(c) If operator efficiency reduced by 20% i.e.

Operator time = $8 \times \frac{(100 + 20)}{100} = 8 \times 1.2 = 9.6$ minutesTotal time = $22 + 9.6 = 31.6$ minutes.Monthly production = $\frac{400 \times 30}{31.6} \times \frac{75}{100} = 284$ Units

(Efficiency reduced by 20%. Instead of 100%, now 80% job is completed in 8 minutes. That means, operators time is increased to 10 minutes)

Illustration 4:

The following data is available for a manufacturing unit :

No. of operators	:	15
Daily working hours	:	8
No. of days per month	:	25
Std. production per month	:	300 units
Std. Labour hours per unit	:	8

The following information was obtained for November 2015:

Man days lost due to absentism	:	30
Unit produced	:	240
Idle Time	:	276 man hours

Find the following:—

- Percent absentism
- Efficiency of utilisation of labour
- Productive efficiency of labour
- Overall productivity of labour in terms of units produced per man per month.

Answer:

No. of days per month = 25

Daily working hrs. = 8

No. of operators = 15

No. of Man days per month = $15 \times 25 = 375$ Man days.

Total working hrs. per month = $375 \times 8 = 3,000$

Hours lost in absentism in a month = $30 \times 8 = 240$

$$(a) \text{ Percent absentism} = \frac{240 \text{ hrs.} \times 100}{3000 \text{ hrs}} = 8\%$$

$$(b) \text{ Efficiency of utilisation of labour} = \frac{\text{Standard labour hour to produce 240 units}}{\text{Total Labour hour}} \times 100$$

$$= \frac{240 \times 8}{3000} \times 100 = 64\%$$

$$(c) \text{ Standard time required to produce 240 units} = 240 \times 8 = 1920 \text{ labour-hours.}$$

$$\text{In November, man hours lost} = 30 \times 8 = 240$$

$$\text{idle time (in hours)} = 276$$

$$\text{Total loss of time} = 516 \text{ hours.}$$

$$\text{Productive hours available in November} = 3000$$

$$\text{Less, Total loss of time} = (516)$$

$$\text{Actual labour-hours} = 2484 \text{ hours}$$

$$\text{Efficiency of labour} = \frac{\text{Std. Labour hrs}}{\text{Actual Labour hrs.}} = \frac{1920 \times 100}{2484} = 77.3\%$$

$$(d) 15 \text{ men produces 300 units,}$$

$$\text{Std. labour productivity} = 300/15 = 20 \text{ units.}$$

$$\text{In November, overall productivity} = 240/15 = 16 \text{ units. (Ans.)}$$

i.e. productivity falls by 25%.

Illustration 5:

An incentive scheme allows proportionate production bonus beyond 100% performance level. Calculate the amount of

(i) Incentive bonus and

(ii) Total payment received by an operator on a particular day during which the following particulars apply:

Operation	:	Assembling pocket transistor radio set
Work Content	:	30 Standard minutes per assembled set
Attended Time	:	8 Hours
Time spent on unmeasured work	:	2 Hours
Numbers of sets assembled during the day	:	15
Wage rate	:	Rs. 4 per hour

(iii) What is the net labour productivity achieved by the operator during the day?

Answer:

Total standard minutes worked during the day = $30 \times 15 = 450$, working time = $8 - 2 = 6$ hours = 360 minutes.

Performance = $(450 \times 100) / 360 = 125\%$ i.e incentive is payable on 25% which is above 100%

(i) Incentive bonus = $0.25 \times 6 \times 4 = \text{Rs. 6}$ for six hours on measured work

(ii) Guaranteed wage for 8 hours = $8 \times 4 = \text{Rs. 32}$; Total earnings for the days

$$= \text{Rs. } (6 + 32) = \text{Rs. } 38$$

(iii) Net labour productivity = Output in units / Net man hours = $15 / 6 = 2.5$ sets per hour.

5.4 ISO Standard Basics

Illustrations From Study Material

Illustration 6:

Compute the productivity per machine hour with the following data. Also draw your interpretation.

Month	No. of machines employed	Working hours	Production Units
January	400	220	99,000
February	550	180	1,00,000
March	580	220	1,25,000

Answer:

Month	No. of machines employed	Working hours	Machine hours	Production Units
January	400	220	88,000	99,000
February	550	180	99,000	1,00,000
March	580	220	1,27,600	1,25,000

P = Productivity per machine hour

= Number of units produced / Machine hours

For January $P = 99,000 / 88,000 = 1.125$

February $P = 100,000 / 99,000 = 1.010$

March $P = 125,000 / 127,600 = 0.980$

Interpretation: Though the total production in number of units is increasing, the productivity is declining.

Illustration 7:

Calculate the standard production per shift of 8 hours duration, with the following data: Observed time per unit = 5 minutes, Rating Factor -120%, Total allowances = 30% of normal time.

Answer:

Normal time per unit = Observed time / unit $\times$ Rating factor = $5 \times (120/100) = 6$ minutes

Allowances = 30% of normal time = $(30 \times 6) / 100 = 1.8$ minutes

Standard time/unit = Normal time/unit + Allowances = $6 + 1.8 = 7.8$ minutes / unit

Standard production in shift of 8 hours = $(8 \times 60) / 7.8 = 61.54$ units.

Illustration 8:

Study in the Packaging Department of a Softdrinks Manufacturing unit revealed the following facts for a worker Basant Rao Patil.

Cycle No.	1	2	3	4	Performance Rating
Activity Element					
(A) Get empty cartoon	0.15 min	0.25 min	—	0.17 min	90%
(B) Place 30 bottles in the cartoon	1.56 min	*	1.80 min	1.75 min	105%
(C) Close the cartoon & set aside	0.20 min	†	0.10 min	0.15 min	95%
(D) Smoking	—	0.50 min	—	—	—

* Bottles slipped out of hands and broke

† Empty cartoon not set aside and used for packaging in the next cycle.

Calculate the standard production by Basant Rao in a shift of 8 hours when the units standard rules allow 10% as Allowance Factor

Answer:

$$\text{Average time for Activity Element A} = \frac{0.15 + 0.25 + 0.17}{3} = 0.19 \text{ min.}$$

$$\text{Average time for Activity Element B} = \frac{1.56 + 1.80 + 1.75}{3} = 1.703 \text{ min.}$$

$$\text{Average time for Activity Element C} = \frac{0.20 + 0.10 + 0.15}{3} = 0.15 \text{ min.}$$

Computation of Normal Time

Activity Element	Average time (Mins)	Performance Rating (%)	Normal Time (Mins)	So Normal Time for the job of packaging = 2.101 Mins
(1)	(2)	(3)	(4) = (2) × (3) ÷ 100	
A	0.19	90	0.171	
B	1.703	105	1.788	
C	0.15	95	0.142	
Total	—	—	2.101	

$$\text{Standard Time} = \frac{\text{Normal Time}}{1 - (\text{Allowance Factor} / 100)} = \frac{2.101}{1 - \frac{10}{100}} = 2.334 \text{ Mins}$$

$$\text{Standard Production in a shift of 8 hours} = \frac{8 \times 60}{2.334} = 205.66 \text{ cartoons.}$$

Illustration 9:

A department works on 8 hours shift, 288 days a year and has the usage data of a machine, as given below:

Product	Annual Demand (units)	Processing time (Standard time in hours)
A	325	5.0
B	450	4.0
C	550	6.0

Calculate (a) Processing time needed in hours to produce products A, B and C, (b) Annual production capacity of one machine in standard hours, and (c) Number of machines required

Answer:

(a) The processing time needed in hours to produce products A, B and C in the quantities demanded using the standard time data:

Product	Annual Demand (units)	Processing time (standard time in hours)	Processing time needed to produce demand quantity (hrs.)
A	325	5.0	325 × 5 = 1,625
B	450	4.0	450 × 4 = 1,800
C	550	6.0	550 × 6 = 3,300
			Total = 6,725 hrs.

(b) Annual production capacity of one machine in standard hours = 8 × 288 = 2,304 hours per year.

(c) Number of machines required = Work load per year / Production capacity per Machine = 6,725 / 2,304 = 2.90 machines = 3 machines.

Illustration 10:

Following results are recorded in a study of work sampling carried for 100 hours in a Machine Shop.

1. Total no. of observations recorded — 2500
2. No. of observations in which no working activity is noticed — 400
3. Ratio of Manual to Machine elements — 2 : 1
4. Average Rating Factor — 115%
5. No. of articles produced during the study period — 6000

As per the policy of the company, rest and personal allowances are taken as 12% of Normal Time. Calculate Standard Time to produce an article.

Given that the shop produces 42000 articles per month of 25 working days by 5 workers working for a shift of 8 hours per day. Consider absentism to be 7%.

Compute Efficiency of utilisation of Labour and Productive Efficiency of Labour.

Answer:

$$\text{Percentage of working time} = \frac{2500 - 400}{2500} \times 100 = 84\%$$

$$\text{Actual working time in a study of 100 hours} = 84 \text{ hours} = 84 \times 60 = 5040 \text{ mins.}$$

Production — 6000 articles

$$\text{Time required to produce an article} = \frac{5040}{6000} = 0.84 \text{ mins}$$

$$\begin{aligned} \text{Of this Manual time} &= 0.84 \times \frac{2}{3} \quad (\because \text{Ratio of Manual to Machine activity elements} = 2:1) \\ &= 0.56 \text{ mins} \end{aligned}$$

$$\text{Machine time} = 0.84 \times \frac{1}{3} = 0.28 \text{ min.}$$

$$\begin{aligned} \text{Normal Time of man} &= \text{Time of man as per study} \times \text{Rating Factor} / 100 \\ &= 0.56 \times \frac{115}{100} = 0.644 \text{ min.} \end{aligned}$$

$$\text{Normal Time of machine} = 0.28 \text{ min.}$$

$$\text{Allowances for man} = 12\% \text{ of Normal time of Man} = 0.12 \times 0.644 = 0.077 \text{ min}$$

$$\begin{aligned} \text{Standard Time for Man to produce an article} &= \text{Normal Time of Man} + \text{Allowances} \\ &= 0.644 + 0.077 = 0.721 \text{ min.} \end{aligned}$$

$$\text{Standard Time for machine} = 0.28 \text{ min.}$$

$$\text{Standard Time to produce an article} = 0.28 + 0.721 = 1.001 \text{ mins.}$$

$$\text{Standard time required to produce 42000 articles} = 42000 \times 1.001 = 42042 \text{ mins.} = 700.7 \text{ hours.}$$

$$\text{No. of days/month} - 25, \text{ Daily working hours} - 8, \text{ No. of workers} - 5$$

$$\text{Total available working hours/month} = 5 \times 25 \times 8 = 1000$$

$$\begin{aligned} \text{Actual working hours/month} &= 1000 \times 0.93 \quad [\text{Since Absentism} = 7\%] \\ &= 930 \end{aligned}$$

$$\begin{aligned} \text{Efficiency of utilisation of Labour} &= \frac{\text{Standard time to produce 42000 articles}}{\text{Total available hours}} \times 100 \\ &= \frac{700.7}{1000} \times 100 = 70.07\% \end{aligned}$$

$$\begin{aligned} \text{Productive Efficiency of Labour} &= \frac{\text{Standard time to produce 42000 articles}}{\text{Actual Working hours}} \times 100 \\ &= \frac{700.7}{930} \times 100 = 75.34\% \end{aligned}$$

Illustration 11:

A cement factory in Madhya Pradesh works 7 days a week in 3 shifts per days having maintenance in the first shift of around 2 hours. It has roughly 100 workers which produces only pozzolanic properties cement better known as PPC. The output per month is around 2500 tonnes of PPC. Find the productivity per worker?

Answer:

Productivity per worker = $2500/100 = 25$ tonnes.

Illustration 12:

Compare the productivity of two plant of tobacco company situated in two different state Y and Z in an 8-hour shift. The standard time in manufacture a tobacco packet is 10 min. The output is 40 and 55 of two different plants in a shift. Find also the expected productivity of both plants in a week.

Answer:

Productivity = Actual production/Standard production

Standard production of tobacco plant is = $8 \times 60 / 10 = 48$ packets.

Productivity of plant located in state Y = $40/48 = 0.833$ (83.33%)

Productivity of plant located in state Z = $55/48 = 1.146$ (114.6%)

Now, expected productivity of plant in Y = $40 \times 7 = 280$ Packets (if it works for 7 days with one shift)

And, expected productivity of plant in Z = $55 \times 7 = 385$ Packets (if it works for 7 days with one shift)

Illustration 13:

For the given data of manufacturing unit which produces spare parts of HEMM the operators time, machine time and total time are 10, 28 and 38 minutes respectively. If there are one operator and working hour per day is 8 hr and considering 22 working days in a month. Find

- If plant is working at 65% efficiency, what is the expected output per month?
- If plant productivity is increased by 20% over the existing level, what will be the output per month?
- If operator efficiency is reduced by 30% due to injury over the existing level, what will be the output per month?

Answer:

Working hours per month = $22 \times 8 = 176$ hrs.

No. of units that can be produced/month by the operator = $176 \times 60/38 = 277.89$ approx 278.

- Now if the plant efficiency = 65% and since there is only one operator and its efficiency is 100% then expected production of spare parts = $277.89 \times 0.65 = 180.62$ Units.
- If the plant efficiency increases by 20% new output will be
New machine time is $28 \times 100/120 = 23.33$ minutes, and then the total time = $10 + 23.33 = 33.33$ min
New monthly production = $277.89 \times (38/33.33) \times 0.65 = 205.93$ Units
- If the operator's efficiency is reduced by 30% then new production will be
New Operator's time = $10 \times (130/100) = 13$ min
So new total time = $13 + 28 = 41$ minutes.
Now new monthly production = $277.89 \times (38/41) \times 0.65 = 167.41$ units

Illustration 14:

Following are the data related to call centre Firm which gives tech and non tech support to large IT companies.

It has 20 executives to address the queries which has 8 hr a shift having on an average 24 working days in month.

On an average the company is able to address around 290 calls in a month.

Additional data for the current month is obtained

(a) No of call logged for the month = 250

(b) Idle time = 275-man hours

(c) Man days lost (absenteeism) = 28.

Find

1. Efficiency of utilisation of manpower
2. Absenteeism (%)
3. Overall productivity of manpower.

Answer:

No of mandays per month = $20 \times 24 = 480$ Man days

Total working hr per month = $480 \times 8 = 3840$.

Hr lost in absenteeism in a month = $28 \times 8 = 224$

1. Efficiency of utilisation of manpower = $(250 \times 8 / 3840) \times 100 = 52.08\%$
2. Absenteeism = $(224 \text{ hr}/3840\text{hr}) \times 100 = 5.833\%$.
3. 20 men logs 290 calls in a month

So the St. manpower productivity = $290/20 = 14.5$ calls.

In the current month overall productivity = $250/20 = 12.5$ calls

So, the productivity has fallen from 14.5 to 12.5 i.e. 13.8%

Illustration 15:

Find the productivity of IT firm in terms of business achieved for the following data and comment

Quarter	No of Employees	Working Hours	Business Achieved (Rs.)
Q1	1600	800	1000000
Q2	1500	750	1024000
Q3	1700	775	1300000
Q4	2000	900	1200000

Answer:

Quarter	No of Employees	Working Hours	Man Hours	Business Achieved (Rs.)	Productivity
Q1	1600	800	1280000	1000000	0.78125
Q2	1500	750	1125000	1024000	0.910222
Q3	1700	775	1317500	1300000	0.986717
Q4	2000	900	1800000	1200000	0.666667

Man hour of Q1 = No of Employee $\times$ Working Hours = $1600 \times 800 = 1280000$

Productivity in Q1 = $1000000/1280000 = 0.78125$

From the above table we can say that the productivity of Q3 is best then follows Q2 then Q1 and the least is Q4.

Illustration 16:

Find the standard production for 8 hr shift. If allowance = 25% of normal time, Observer time per unit is 7 min and the rating factor is 110%.

Answer:

Normal time per unit = Observed time / unit × Rating factor = $7 \times (110/100) = 7.7$ minutes

Now, Allowances = 25% of normal time = $(25 \times 7.7)/100 = 1.925$ minutes.

So, Standard time/unit = Normal time/unit + Allowances = $7.7 + 1.925 = 9.625$ minutes / unit

Hence, Standard production in shift of 8 hours = $(8 \times 60)/9.625 = 49.89$ units (50 Units approx.)

Illustration 17:

A captive plant works for one shift in a day i.e. 8 hr a shift for 200 days in a year to cater for large automobile company. It produces three product having annual demand as 425, 429 and 546 units respectively. The processing time (standard time in hr) are 4, 5 and 5.5 hours respectively. Calculate

(a) Processing time required to produce all three products.

(b) Annual production

(c) And number of machine required.

Answer:

(a) Product 1 → Processing time needed to produce demand quantity (hrs.) = Annual Demand × Processing time (Standard time in hr) = $425 \times 4 = 1700$ hrs

Product 2 → Processing time needed to produce demand quantity (hrs.) = $429 \times 5 = 2145$ hrs

Product 3 → Processing time needed to produce demand quantity (hrs.) = $546 \times 5.5 = 3003$ hrs.

Hence total time needed = 6848 hrs.

(b) Annual production capacity for a single machine = $8 \times 200 = 1600$ hrs for a year.

(c) Minimum number of machines required = $6848/1600 = 4.29$ (5 machine Approx.)

Illustration 18:

Below data are collected related to work study for 150 hrs on a floor shop employing 7 labours having a shift of 8 hrs in a day.

(a) Number of observations documented in total = 3000

(b) Number of observations in which no working activity is observed = 500

(c) Manual to machine ratio = 3:2

(d) Average Rating factor = 120%

(e) Number of product produced during the period of study = 7000

Company has its own policy regarding personal allowance which is pegged at 11% of normal standard time to produce a product.

The floor shop produces 49000 products per month for 24 working days, it has an absenteeism of around 6%.

Calculate efficiency of utilisation of Labour and Productive Efficiency of Labour.

Answer:

Percentage of working time = $((3000-500)/3000) \times 100 = 83.33\%$

Actual working time in a study of 150 hrs = $150 \times 0.8333 \times 60 = 7500$ min.

Production = 7000 units.

Time required for one unite to produce = $7500/7000 = 1.0714$ min

So, manual time on this is $1.0714 \times (3/5) = 0.643$ mins and machine time is $1.0714 \times (2/5) = 0.43$ mins.

Normal time of labour = time of labour as per study $\times$ Rating Factor/100 = $0.643 \times 120/100 = 0.772$ min.

And normal time of machine = 0.43 min.

Now, if allowance is considered which is 11% of normal time which bring the standard time for the labour to produce = $0.772 \times 1.11 = 0.857$ min.

Hence Standard time required to produce a product = $0.857 + 0.43 = 1.286$ min.

And. Standard time required to produce 49000 units = $49000 \times 1.286 = 63,038$ min = 1050 hrs.

Now, total available working hrs for 24 working day of 8 hrs shift of 7 labours = 1344 hr in a month

Taking absenteeism in consideration actual working hour left = $1344 \times 0.94 = 1263.4$ hrs.

Efficiency of utilisation of Labour = $1050/1344 = 0.7813$ (78.13%)

And

Productive efficiency of Labour = $1050/1263.4 = 0.8312$ (83.12%)

THEORY QUESTIONS

Question 1: What is Productivity?

Productivity is a crucial measure in any production process. It quantifies how much input is required to achieve a given output. This relationship can be symbolically expressed as:

$$P = O/I$$

Where:

- P = Productivity
- O = Output
- I = Input

Example: In a car manufacturing plant like Maruti Suzuki, productivity might measure how many cars are produced (output) given the amount of labor and materials used (input). If the plant can produce 1,000 cars using 5,000 hours of labor, increasing productivity would mean producing more cars with the same or fewer hours.

Example: At a software development company like Infosys, productivity could be evaluated by the number of software modules completed (output) relative to the number of developer hours spent (input). Enhancing productivity means delivering more modules in the same time frame, improving efficiency.

Question 2: Explain the importance of the concept of Productivity?

Possible replication Questions

1. How does improved productivity help firms to compete effectively in the market?
2. Discuss the strategic, tactical, and planning uses of productivity indices in management.
3. Explain how productivity is an indicator of progress in developing countries.
4. What role does productivity play in the optimal utilization of scarce resources?
5. Describe the various ways in which higher productivity benefits both the firm and its employees.

Concept Book: The Importance of Productivity

Mnemonic Anchor: "BIG MAP COP"

To remember the key points, use the mnemonic **BIG MAP COP**:

Letter	Stands for
B	Beat the Competition
I	Indicator of Progress
G	Guide to Management
M	Maximum Utilisation of Scarce Resources
A	Administration (under Guide to Management)
P	Planning (under Guide to Management)
C	Competitive Strength (Other Uses)
O	Other Uses
P	Prosperity (National & Workforce)

1. To Beat the Competition

It is an age of cut-throat competition. There may be other commodities which can serve as the substitute of a particular 'product' and can attract the consumers' for purchasing. The firm whose productivity is higher can only beat the competition and can exist in the market for long.

Example: In the automobile industry, Maruti Suzuki maintains market dominance by producing fuel-efficient cars at competitive prices.

2. Guide to Management

The productivity indices are very useful for the management and can be used for different purposes. These indices can serve as a valuable guide to the management for improving the performance of its enterprise. The productivity measures can be used for the following purposes:

a) Strategic

With the help of productivity indices, the efficiency of different firms can be measured, analysed and compared. The necessary steps can be taken to improve the productiveness of the firm taking in view the productiveness of the other competitive firms.

Example: Comparing productivity between telecom giants like Airtel and Jio helps identify strategic gaps.

b) Tactical

Different units or the sectors of the firm can also be compared as regards to their productivity and the productivity of the less productive units or sectors can be improved.

Example: A hospital may compare its emergency and outpatient departments to optimize staffing and workflows.

c) Planning

A firm uses different inputs in producing the goods. A comparison of relative benefits accruing from the use of different inputs can be done and the most beneficial input can be used in production. It helps the management to plan for the future.

Example: A textile firm may choose automated looms over manual ones after analyzing input-output ratios.

d) Administration

Productivity indices indicate the progress of the firm over a period of years. The productivity of different inputs, including labour, can be measured individually. The individual productivity indices help the management in bargaining with the labour leaders, trade unions and the Government in case of labour disputes regarding welfare activities. Thus administration can be improved with the help of productivity indices.

Example: A manufacturing firm may use labor productivity data to justify wage revisions during union negotiations.

3. An Indicator of Progress

In economically backward countries, productivity improvement is the basic aspect of progress. It implies the development of an attitude of mind and a constant urge to go for better, cheaper, quicker and safer ways of doing a job which could be either manufacturing a product or providing a service. In an urge to improve the productivity, new inventions take place. Thus productivity is an aspect of basic progress.

Example: In India's rural banking sector, digitization has improved service delivery and financial inclusion.

4. Maximum Utilisation of Scarce Resources

In order to provide the articles or commodities to the consumers at the lowest possible cost, the productivity urges to utilise the available resources to the maximum possible extent so that there is full satisfaction of customers. The productivity processes and techniques are designed to facilitate more efficient work involving less fatigue to the workers by improvement in the layout of the plant, better working environment and simplification of works.

Example: IKEA's flat-pack design maximizes logistics efficiency and reduces costs for consumers.

5. Key to National Prosperity

The productivity, in fact, has become synonymous to the progress. Higher productivity is an index of more production with the same inputs at lower cost. It enables industry to offer goods to the general public at cheaper rates and results in expansion of markets. The working conditions and wages of workers will improve and industrialists too will get larger profits. Thus higher productivity is the key to national prosperity. The secrets of Japan, China, South Korea and Western countries' prosperity lie in increased productivity.

Example: South Korea's rise in electronics and shipbuilding is rooted in productivity-focused reforms.

6. Prosperity to Work Force

The higher productivity is a boon to workers also. It brings improved working conditions, better wages and salaries, better welfare activities for labourers, etc. Thus their standard of living is going to be improved.

Example: Infosys and TCS invest in employee upskilling, leading to better productivity and compensation.

7. Other Uses

i. Expansion and Modernisation

Higher productivity increases the profits and reserve funds of the industry that can be used for expansion and modernisation.

ii. Goodwill of the Firm

It increases the goodwill of the firm due to cheaper goods to the public, well-off staff and more profits and better financial position.

iii. Competitive Strength in Export Markets

It improves the competitive strength of the company in export markets through reduction in cost of production and quality products.

In this way, productivity is the only way to make the overall progress of the country.

Example: India's pharmaceutical exports thrive due to cost-effective production and global quality standards.

Final Recap: BIG MAP COP

- Beat the Competition
- Indicator of Progress
- Guide to Management
- Maximum Utilisation
- Administration
- Planning
- Competitive Strength
- Other Uses
- Prosperity

Measurement of Productivity

Question 3: Productivity can be measured by either changes in input or by changes in output, Explain ?

Concept Book: Measurement of Productivity

Core Concept

- i. Productivity or the performance of various input and output factors can be measured in two ways. Criterion 1: Output per Unit of Input

Change in output per unit of input indicates the change in the performance of corresponding input during the given period, e.g., change in output per worker or per man-hour will signify the change in performance of labour.

Example: If a factory worker produced 10 units per hour last month and now produces 12 units per hour, the productivity of labour has improved.

Criterion 2: Input per Unit of Output

- ii. Change in input per unit of output during a given period signifies the change in the performance of the corresponding input factor, e.g., change in man-hour or workers' per unit of output will also indicate the change in the performance of the labour input.

Example: If it took 5 man-hours to produce one unit last month and now it takes only 4 man-hours, the labour input has become more efficient.

Mnemonic: "O-I / I-O"

To remember the two criteria, use the simple mnemonic:

Mnemonic	Meaning
O-I	Output per unit of Input
I-O	Input per unit of Output

Summary Table

Criterion	Description	Example
Output per Unit of Input	Measures how much output is generated per input	Output per worker or per man-hour
Input per Unit of Output	Measures how much input is required per output	Man-hours per unit of output

Different Types of Productivity Indices

Question 4: What are the different types of Productivity Indices ?, How they can be measured?

Productivity Indices

Introduction

Some of the well-known indices of productivity are given below:

Man-hour Output

The most widely used index of productivity is to work out the output per man-hour. It can be put as:

Productivity = Units of output / Total man-hours

Example: If a factory produces 1,000 units using 500 man-hours,

Productivity = 1,000 / 500 = 2 units per man-hour

This index helps assess how efficiently labor time is being converted into output.

Productivity Ratio

The rate of return on capital employed is a valuable and widely used guide to many types of business decisions. This ratio of profit to capital employed is a valuable means of measuring the performance of divisions, sections, plants, products and other components of a business, and can be calculated as:

Productivity = Net Profit / Capital employed

Example: If Net Profit = ₹20 lakh and Capital Employed = ₹1 crore,

Productivity = 20 / 100 = 0.2 or 20%

This ratio helps compare profitability across business units.

Use of Financial Ratios

There are many situations when time standards cannot be set and therefore, it is very difficult in such cases to measure the productivity by a direct method.

In these cases, financial ratios can be used to measure the productivity by using its sales turnover.

But 'added value' is a more useful approach for measuring productivity.

Added value' means output - inputs.

Most Common Financial Ratios:

- **Productivity = Added Value / Labour Costs**
- Gives the financial productivity of labour force
- **Productivity = Added Value / Conversion Costs**
- Gives the financial productivity of all the resources of the company put together

Example: If Added Value = ₹50 lakh and Labour Costs = ₹10 lakh, **Productivity = 50 / 10 = 5**

This means ₹5 of value is generated for every ₹1 spent on labour.

Other Useful Measures

There are many other useful productivity ratios to measure the productivity of various input factors.

These are:

i. Manpower Productivity

Manpower Productivity = Value of output of goods or services / No. of workers or man hours used

Example: Output = ₹80 lakh, Man-hours = 8,000 **Productivity = ₹80,00,000 / 8,000 = ₹1,000 per man-hour**

ii. Material Productivity

Material Productivity = Value of output of goods or services / Units (or cost) of materials used

Example: Output = ₹60 lakh, Material Cost = ₹15 lakh **Productivity = 60 / 15 = 4**

iii. Capital Productivity

Capital Productivity = Value of output of goods or services / Value of capital employed

Example: Output = ₹90 lakh, Capital Employed = ₹30 lakh **Productivity = 90 / 30 = 3**

iv. Energy Productivity

Energy Productivity = Value of output of goods or services / Units (or cost) of energy used

Example: Output = ₹50 lakh, Energy Cost = ₹10 lakh **Productivity = 50 / 10 = 5**

v. Combined Productivity

A combined measure of productivity can be taken as: **Combined Productivity = Value of output of goods or services / Values of (labour + capital + materials + other inputs)**

Example: Output = ₹1 crore, Total Input Cost = ₹40 lakh **Productivity = 100 / 40 = 2.5**

There may be other input factors such as insurance, taxes, advertising etc. and their productivity can be measured likewise.

Each measure requires different kinds of data and only rarely such information is available for all commodities in an industry on continuous basis.

Summary Table

Index Type	Formula	Measures What?
Man-hour Output	Units of output / Total man-hours	Labour efficiency
Productivity Ratio	Net Profit / Capital employed	Return on capital
Labour Financial Ratio	Added Value / Labour Costs	Financial productivity of labour
Conversion Cost Ratio	Added Value / Conversion Costs	Financial productivity of all resources
Manpower	Value of output / No. of workers or	Workforce efficiency

Productivity	man-hours	
Material Productivity	Value of output / Material cost	Material usage efficiency
Capital Productivity	Value of output / Capital employed	Capital efficiency
Energy Productivity	Value of output / Energy cost	Energy usage efficiency
Combined Productivity	Value of output / Total input costs	Overall input efficiency

Concept Book: Tools of Productivity / How to Increase Productivity

Question 5:

1. What are the different ways to increase productivity in an enterprise?
2. Explain how Human Aspects contribute to improving productivity. Give suitable examples.
3. Describe the role of Supply of Inputs in enhancing productivity. How can better materials and equipment help?
4. What are the Technological methods used to improve productivity? Explain with examples.

Introduction

The productivity of an enterprise can be improved by improving the performance of various inputs and other factors affecting productivity. For this purpose, use of following tools can be recommended.

Mnemonic: HST Formula

To remember the three major categories of productivity tools, use the mnemonic:

Letter	Stands for
H	Human Aspects
S	Supply of Inputs
T	Technological Aspects

1. Human Aspects

Under this, cooperation of workers is sought in the following ways:

- More workers participation in management or in decision making through joint consultation.**
Example: A factory forms a joint consultative committee where workers suggest improvements in shift scheduling.
- Improving communication services.**
Example: Installing internal messaging systems or suggestion boxes to streamline feedback.
- Improving mutual trust and cooperation through improved job procedures, better training of employees, more workers incentives by implementing various incentive schemes, and labour welfare programmes.**
Example: A company introduces performance-linked bonuses and skill development workshops.
- Better planning of work, more effective management, more democracy in administration, improved human relations and selection and training of personnel at various levels of management are some human efforts from the side of management in order to improve the productivity.**
Example: A retail chain decentralizes decision-making and trains store managers in leadership and conflict resolution.

2. Supply of Inputs

- Improvement in the nature and quality of raw materials and their supplies to the work.**
Example: A textile firm switches to higher-grade cotton to reduce defects and increase output.
- Proper provision of plant, equipment and their maintenance.**

Example: A manufacturing unit schedules monthly maintenance to avoid breakdowns and downtime.

iii. **Introduction of more and more machines and equipment in place of physical work.**

Example: A warehouse installs automated conveyor belts to reduce manual lifting.

iv. **Fuller utilisation of manpower and efficiency or capacity of plant and equipment employed.**

Example: A production line is restructured to ensure every machine and worker is optimally engaged.

3. Technological Aspects

Certain methodological and technological developments are also necessary to improve the productivity of the concern.

i. **Work, time and motion studies to determine better ways and means of doing a job.**

Example: A logistics firm conducts motion studies to reduce unnecessary steps in packaging.

ii. **Implementing various simplification, specialisation and standardisation programmes.**

Example: A fast-food chain standardizes its burger assembly process to reduce preparation time.

iii. **Applying control techniques comprising of production, planning and control, cost control and quality control techniques.**

Example: A pharma company uses ERP software for integrated cost and quality control.

iv. **Improving layout of plants, shops and machine tools, and material handling and internal transportation system.**

Example: A car manufacturer redesigns its assembly floor to minimize movement and maximize flow.

v. **Improving inspection techniques so as to minimise the wastage and defective work.**

Example: A food processing unit installs automated scanners to detect packaging defects.

Summary Table

Category	Tool / Technique	Example
Human Aspects	Joint consultation, communication, training, incentives, democratic management	Worker committees, bonus schemes, HR workshops
Supply of Inputs	Quality raw materials, equipment maintenance, mechanization, full utilization	High-grade inputs, automation, preventive maintenance
Technological	Time-motion studies, standardization, control techniques, layout improvement	ERP systems, plant redesign, automated inspection

Concept Book: Factors Affecting Industrial Productivity

Question 6: What are the major Factors affecting Industrial Productivity ?

Introduction

The productivity of an enterprise can be improved by improving the performance of various inputs and other factors affecting productivity. For this purpose, use of following tools can be recommended.

Mnemonic: TIOWE-GEN

To remember the five major categories of factors, use the mnemonic:

Letter	Stands for
T	Technological Development
I	Individual Factors
O	Organisation Factors
W	Work Environment
E-GEN	External (Natural, Managerial, Government)

1. Technological Development

Technical factors including the degree of mechanisation, technical know-how, raw materials, layout and the methods and techniques of work determine the level of technological development in any industry.

Principal Factors:

- **The Size of the Plant** ➤ Production below or above the optimum level will be uneconomical and will tend towards lower level of productivity.
Example: A small plant running oversized machinery may waste energy and resources.
- **Research and Development** ➤ Investment in research and development may yield better method of work and better design and quality of products.
Example: Pharma companies invest in R&D to create more effective drugs.
- **Plant and Job Layout** ➤ Arrangement of machines and positions in the plant and the set-up of the work-bench of an individual worker will determine how economically and efficiently production will be carried out.
Example: Assembly lines in automobile factories are designed for minimal movement.
- **Machine and Equipment Design** ➤ Modern design aligned with worker capabilities improves production efficiency.
Example: Ergonomic tools reduce fatigue and increase output.
- **Production Processes** ➤ Use of modern integrated and automatic machinery and semi-processed materials helps raise productivity.
Example: Robotics in electronics manufacturing speeds up precision tasks.
- **Power, Raw Materials etc.** ➤ Improved quality of raw materials and increased use of power have a favourable effect on productivity.
Example: High-grade steel in construction reduces waste and rework.
- **Scientific Management Techniques** ➤ Better planning, simplification, time and motion study, reduced wastage and spoilage improve productivity.
Example: Lean manufacturing principles in Toyota's production system.

Technological development requires funds and a supportive economic and technical environment. Capital plays a key role. Better machines and processes improve both ability and willingness to work.

2. Individual Factors

Individual factors such as knowledge, skill and attitude also affect the productivity of industry.

- **Knowledge**
 - Acquired through training, education and interest.
Example: A trained CNC operator performs tasks faster and more accurately.
- **Skill**
 - Affected by aptitude, personality, education, experience, training.
Example: Skilled welders reduce defects and improve safety.
- **Attitude**
 - Willingness to work for the organisation is crucial.
Example: Motivated employees often exceed performance targets. Knowledge and skill without willingness are futile. The urge to work is influenced by organisation, leadership, satisfaction, trade unions etc.

3. Organisation Factors

Organisation factors include steps taken to maintain better industrial relations.

Key Elements:

- Delegation and decentralisation of authority
 - Participative management
 - Organisational efficiency
 - Personnel policies: selection, placement, promotion, wage, salary, incentives, merit rating, job evaluation, training
 - Two-way communication and supervision
- Example: Infosys uses participative management and transparent HR policies to boost productivity. Existence of high-productivity groups contributes to organisational goals. Hawthorne experiments in U.S.A. highlighted the role of motivation.

4. Work Environment

Proper work environment and physical conditions on the job are vital.

Includes:

- Better ventilation and lighting
- Improved safety devices
- Reduction in noise
- Suitable rest-pause arrangements

Example: IT companies provide ergonomic workstations and wellness zones to enhance focus and comfort.

5. Other Factors**a) Natural Factors**

Physical, geographical and climatic conditions influence productivity. Example: Coastal regions may benefit from easier logistics, while extreme climates may reduce worker efficiency.

b) Managerial Factors

Managerial ability and leadership affect productivity. Example: A visionary leader can reorganize operations for better resource utilization.

c) Government Policy

Taxation, financial, administrative, tariff and protection policies affect productivity. Example: Subsidies for solar energy equipment boost productivity in green manufacturing.

Thus, the above factors are responsible for the increased productivity.

Summary Table

Category	Key Elements & Examples
Technological	R&D, plant layout, machinery, scientific techniques
Individual	Knowledge, skill, attitude, motivation
Organisation	HR policies, decentralisation, participative management
Work Environment	Safety, lighting, ventilation, rest-pause
Other Factors	Natural resources, leadership, government policy

Concept Book: Total Quality Management (TQM)

Question 7:

1. What is Total Quality Management (TQM)? Explain its key principles with suitable examples.
2. Describe the basic concepts of Total Quality Management. How do they help in achieving customer satisfaction?
3. Explain the role of top management, employees, and suppliers in implementing Total Quality Management.
4. How does TQM promote continuous improvement and performance measurement in organisations? Give examples.

Definition

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**
Example: Toyota's leadership actively promotes quality circles and Kaizen initiatives.
2. **Focus on both internal and external customers**
Example: Internal customers may be departments within the organisation; external customers are end users.
3. **Employee involvement and empowerment**
Example: Infosys encourages employees to suggest process improvements via internal forums.
4. **Continuous improvement (KAIZEN)**
Example: Japanese firms like Canon and Sony use Kaizen to refine operations daily.
5. **Partnership with suppliers**
Example: Ford collaborates with suppliers to ensure quality components and timely delivery.
6. **Establishing performance measures for processes**
Example: A call centre may track average handling time and customer satisfaction scores.

Essentials of TQM Focus

1. **Customer satisfaction**
➤ Meeting or exceeding customer expectations.
2. **Leadership**
➤ Driving the quality vision and culture.
3. **Quality policy**
➤ A formal statement of commitment to quality.
4. **Organisation structure**
➤ Designed to support quality initiatives.
5. **Employee involvement**
➤ Active participation in quality improvement.
6. **Quality costs**
➤ Includes prevention, appraisal, and failure costs.
7. **Supplier selection and development**
➤ Choosing reliable suppliers and helping them improve.
8. **Recognition and reward**
➤ Acknowledging contributions to quality improvement.

Underlying Principles in TQM

Question 8: What are the underlying Principles of TQM

1. **Strive for quality in all things (Total Quality)**
Example: Apple focuses on design, packaging, and user experience.
2. **The customer is the creation of quality** ➤ Quality is defined by customer needs and expectations.
3. **Improve the process or systems by which products are produced** Example: Amazon optimizes its logistics and delivery systems.
4. **Quality improvement is continuous, never-ending activity (Kaizen)** ➤ Small, incremental changes lead to long-term gains.
5. **Worker involvement is essential** ➤ Employees closest to the process often have the best insights.
6. **Ground decisions and actions on knowledge** ➤ Use data and analysis, not assumptions.
7. **Encourage team work and cooperation**
Example: Cross-functional teams in Samsung work on product innovation.

Productivity Management and Quality Management

TQM integrates quality improvement with productivity enhancement. Better quality reduces rework, waste, and inefficiencies—leading to higher productivity.

Scope of TQM

1. **An integrated organisational infrastructure** ➤ Quality is embedded in every department and function.
2. **A set of management practices** ➤ Includes planning, control, and continuous review.
3. **A wide variety of tools and techniques** ➤ Flow charts, check sheets, histograms, Pareto analysis, scatter diagrams, etc.

Question 9: What is TQM, What are the three underlying Philosophies of TQM**Japanese Approach to Quality**

TQM is a Japanese approach to quality

The term TQM refers to a quest-for quality in an organisation.

Three Core Philosophies of TQM

1. **Never-ending push to improve (Continuous Improvement)**
2. **Involvement of every employee in the organisation**
3. **Goal for customer satisfaction (meeting or exceeding expectations)**

Key Elements of TQM

- **Team approach**
- **Employee empowerment**
- **Decisions based on facts rather than opinions**
- **Knowledge of quality tools** ➤ Flow charts, check sheets, histograms, Pareto analysis, scatter diagrams etc.
- **Quality at the source**
- **Inclusion of suppliers as a part of quality improvement programme**

Central Focus: Customer Satisfaction

TQM is a process of continuous improvement at every level of the organisation—the centre of the entire process is customer satisfaction.

TQM implies that the organisation is doing everything it can to achieve quality at all stages of the process, from customer demands, to product design, to engineering.

Distinguish between ISO 9000 and ISO 14000

Alternative Essay Questions:

Question 10:

1. How do ISO 9000 and ISO 14000 certifications contribute to organizational improvement?
2. Discuss the importance of ISO 9000 in ensuring customer satisfaction and product quality.
3. Explain the role of ISO 14000 in promoting environmental sustainability.

Concept Book: Quality Certification

Introduction

Many international businesses recognize the importance of quality certification. The EU, in 1987, established ISO [International Organisation for Standardisation] 9000 certification. Two of the most well known of these are ISO 9000 and ISO 14,000. ISO 9000 pertains to quality management. It concerns what an organisation does to ensure that its products or services are suitable to customers expectations. ISO 14,000 concerns minimization of harmful effects to the environment caused by its operations. Both ISO 9000 and ISO 14000 are related to an organisations processes rather than its products and services and they stress continual improvement.

Global Adoption

ISO 9000 is composed of the national standard bodies of 91 countries. About 90 countries have adopted ISO 9000 as national standards. This certification is intended to promote the idea of quality at every level in the organisation.

Certification Process

ISO certification is an elaborate and expensive process. Any firm seeking this certification needs to document how its workers perform every function that affects quality and install mechanisms to ensure that, they follow on expected lines. ISO 9000 certification entails a complex analysis of management systems and procedures. Rather than judging the quality of a particular product, ISO 9000 evaluates the management of the entire manufacturing process, from purchasing, to design, to training. A firm that seeks this certification must fill out a report and then be certified by a team of independent auditors. With certification comes registration in an ISO directory, that firms seeking suppliers can refer to, for a list of certified companies. They are generally given preference over unregistered companies.

ISO 9000 Series: Standards and Guidelines

There are essentially five standards associated with the ISO 9000 series.

The series, if we place them on a continuum, would range from design and development through procurement, production, installation and servicing.

Whereas, ISO 9004 only establishes guidelines for operation, ISO 9001, 9002 and 9003 are well-defined standards.

Quality System

• 9001

Model for Quality Assurance in Design, Production, Installation and Servicing (To be used when conformance to specified requirements is to be assured by the supplier during several stages that may include design/development, production, installation and servicing).

• 9002

Model for Quality Assurance in Production and Installation (To be used when conformance to specified requirements is to be assured by the supplier during production and installation).

• 9003

Model for Quality Assurance in Final Inspection Test. (To be used when conformance to specified requirements is to be assured by the supplier solely at final inspection and test).

Guidelines for Use

- **9000**
Quality Management and Quality Assurance Standards - Guidelines for Selection and Use.
- **9004**
Quality Management and Quality System Elements - Guidelines.

ISO 9000 Standards, Their Areas of Application in Production Flow and Guidelines for Use

Stage	Applicable ISO Standard
Design/Development	ISO 9001
Procurement	ISO 9001
Production	ISO 9002
Installation	ISO 9002
Servicing	ISO 9001
Final Inspection	ISO 9003

Figure 5.2: Production flow and Guidelines for use**Importance in Global Trade**

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.

Eight Quality Management Principles (ISO 9001:2015)**Question 11:**

"What are the eight Quality Management Principles outlined in ISO 9001:2015? Explain how these principles help organizations adapt to modern business challenges."

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.

QUESTIONS FROM PYP'S

Question 1.**(Dec 23 4M)**

Identify underlying principles in TQM.

Answer:

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 teamwork and cooperation

Question 2.**(Jun 23 4M)**

The Quantitative Parameters pertaining to a machine extracted from the records of a manufacturing unit of SONIX Ltd. are as given below:

Description	Value
Working days per month	25
Hours worked per day	8
Standard Minutes per unit of production:	
Operator Time (Minutes)	12
Machine Time (Minutes)	36
Total time per unit (Minutes)	48
Number of Operators	1
Number of Machines	1

No. of Units to be rounded off to the nearest integer)

Required:

- (1) If the plant is operated at 80% efficiency and the operator is working at 100% efficiency, calculate the output (units) per month.
- (2) If the Machine productivity is reduced by 10% over existing level, assess the output (in units) per month.

Answer:

- 1) Hours worked per day = 8
 Working days per month = 25
 Hours worked per month = $25 \times 8 = 200$ hours
 Machine time = 36 minutes
 Operation time = 12 minutes
 Total time/unit = 48 minutes = 0.8 hour
 No. of units that can be produced/month/operation = $200/0.8 = 250$
 As the no. of operation is 1, possible monthly production = 250 units.
 As the plant operates at 80% efficiency, monthly production = $250 \times 80\% = 200$ units.
- 2) If machine productivity is reduced by 10% i.e., Machine time = $36 \times 100/90 = 40$ minutes
 Then, total time = $40 + 12 = 52$ minutes
 Monthly production = $25048/52 \times 80\% = 184.62$ units, ~185 units (approx.)

Question 3.**(Jun 23 4M)**

INTOX LTD. (IL), an engineering organisation having 40 operators, works 25 days in a month, with a single shift of eight hours. The standard production per month is 650 units while the standard man-hours/unit are 10.

In the month of April 2023, 90 days were lost due to absenteeism. The company produced 524 units while the idle time logged by operators was 728 man-hours in April 2023. You are required to ascertain:

- (i) Absenteeism (%)
- (ii) Labour utilisation (%)
- (iii) Productive efficiency of labour(%)
- (iv) The overall productivity of labour in terms of units produced per man-hour per month.

Answer:

i) Present absenteeism = (No of Hrs lost in absenteeism in a month)/Total working Hours per month $\times 100$

$$= 90 \times 8 / 40 \times 25 \times 8 \times 100 = 9\%$$

ii) Efficiency of utilization of Labour = Standard labour hour to produce 524 units/Total Labour Hour $\times 100$

$$= 524 \times 10 \times 100 = 65.5\%$$

- iii) Determination of Productive efficiency of Labour:

Standard time required to produce 524 units = $524 \times 10 = 5240$ Labour hours

In April, 2023, man hours lost = $90 \text{ days} \times 8 = 720$ hours

In April 2023, Idle time (in hours) = 728 hours
= 1448 hours

Productivity hours available in April 2023 = $40 \times 25 \times 8 = 8000$ hours

Less: Total loss of time (1448 hours)

Actual labour Hours = 6552 hours

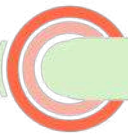
Productive efficiency of Labour = Standard Labour Hours/Actual Labour Hours $\times 100$
= $5240 / 6552 \times 100 = 79.98\%$

- iv) Overall productivity of labour in terms of units produced per month:

Standard Labour Productivity = $650 \text{ units} / 40 \text{ operations} = 16.25$

Overall productivity = $524 \text{ units} / 40 \text{ operators} = 13.1$

i.e., Productivity falls by $(16.25 - 13.1) / 16.25 \times 100 = 19.38\%$



MODULE 6: PROJECT MANAGEMENT, MONITORING AND CONTROL

Questions For Classroom Discussion

Question 1

Draw the network diagram to the following activities

Activity	Time Duration
1 to 2	2
1 to 3	4
1 to 4	3
2 to 5	1
3 to 5	6
4 to 6	5
5 to 6	7

Question 2

A project schedule has the following characteristics.

Activity	Duration
1 to 2	4
1 to 3	1
2 to 4	1
3 to 4	1
3 to 5	6
4 to 9	5
5 to 6	4
5 to 7	8
6 to 8	1
7 to 8	2
8 to 10	5
9 to 10	7

Q.1 Construct network diagram

Q.2 Compute earliest latest time for each event

Q.3 Find EST, LST, EFT, LFT values and Total Float of all activities

Q.4 Find critical path and project duration.

Question 3

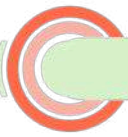
A project has the following time schedule.

Q.1 Construct network diagram

Q.2 Compute EST, LST, EFT, LFT and Total Float of all activities.

Q.3 Find critical path and its duration.

Activity	Duration
1 to 2	2
1 to 3	2



1 to 4	1
2 to 5	4
3 to 6	8
3 to 7	5
4 to 6	3
5 to 8	1
6 to 9	5
7 to 8	4
8 to 9	3

Question 4

A project has the following time schedule.

Q.1 Construct network diagram

Q.2 Compute Earliest and Latest Event time

Q.3 Compute EST, LST, EFT, LFT and Total Float of all activities.

Question 5

Find critical path and its duration.

Activity	Duration
1 to 2	20
1 to 3	25
2 to 3	10
2 to 4	12
3 to 4	6
4 to 5	10

Program Evaluation and Review Technique (PERT)

Question 6

Assuming that the expected time are normally distributed.

Find critical path and project duration.

Activity	Optimistic	Most Likely	Pessimistic
1 to 2	2	5	14
1 to 3	9	12	15
2 to 4	5	14	17
3 to 4	2	5	8
3 to 5	8	17	20
4 to 5	6	9	12

Computation of Probability

<u>Less Than</u> If Z is +ve Probability = $0.5 + \text{Table Value}$ If Z is -ve	<u>Greater Than</u> If Z is +ve Probability = $0.5 - \text{Table Value}$ If Z is -ve

Probability 0.5 - Table Value	Probability = 0.5 + Table Value

Question 7

Mean and Standard Deviation of a project duration are 300 and 100 days respectively. Find the probability for

Q.1 Completing the project within 417 days

Q.2 Not completing within 417 days

Q.3 Completing the project within 183 days

Q.4 Not completing within 183 days.

(Area under normal distribution from $z = 0$ to $z = 1.17$ is 0.3790)

Standard Normal Distribution Table

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890

2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990

Question 8

A project is expected to take 15 months along the critical path having standard deviation of 3 months. What is the probability of completing the project

Q.1 Within 18 months

Q.2 Within 12 months

Area Under Standard Normal Curve from $Z=0$ to $Z=1$ is 0.3413

Question 9

Q.1 Draw Network Diagram

Q.2 Calculate length and variance of the critical path

Q.3 What is the approximate probability that jobs on the critical path will be completed within (a) 41 days (b) 35 days.

Q.4 What is the probability that the project will not be completed within 45 days.

Area under normal distribution from $z=0$ to $z=1$ is 0.3413

Area under normal distribution from $z=0$ to $z=0.2$ is 0.0793

Area under normal distribution from $z=0$ to $z=1.8$ is 0.4641

Three Important Questions

Question 10

A project consists of five activities. Activities P and Q run simultaneously. The relationship among the various activities is as follows.

Activity	Immediate Successor
P	R
Q	S

Activity T is the last operation of the project and it is also immediate successor to R and S.

Draw the network of the project.

Question 11

A project work consists of seven activities. Activities P,Q,R run simultaneously. The relationship among various activities is as follows.

Activity	Immediate Successor
P	S
Q	T
R	U

Activity "v" is the last operation of the project and it is also immediate successor to S,T, and U.
Draw the network diagram.

Question 12

Project with the following data is to be implemented. Draw the network diagram and find the critical path.

Activity	Predecessor	Duration	Cost
A	-----	2	50
B	-----	4	50
C	A	1	40
D	B	2	100
E	A,B	3	100
F	E	2	60

Q.1 What is the minimum duration of the project?

Q.2 Draw a Gantt chart for early start schedule

Time cost Trade off Analysis- Crashing

The following table gives duration in days and cost of the activities for a project

Activity	Normal Time	Crash Time	Normal Cost	Crash Cost
1 to 2	4	3	600	800
1 to 3	2	2	400	400
1 to 4	5	4	750	900
2 to 3	7	5	400	600
2 to 5	7	6	800	1000
3 to 5	2	1	500	650
4 to 5	5	4	600	850
			4050	

Indirect cost per day is Rs 200

Q.1 Draw the network of the project

Q.2 Find normal duration and cost of the project

Q.3 Find the optimum duration and cost of the project.

Question 13

Construct the network for each of the projects whose activities and their precedence relationships are as given below:

Activity	A	B	C	D	E	F	G	H	I	J	K
Immediate Predecessor	-	-	-	A	B	B	C	D	E	H, I	F, G

Illustration From Study Material

Illustration 1:

A project consists of seven activities. Activities P, Q, R run simultaneously. The relationships among the various activities is as follows:

Activity	Immediate Successor
P	S
Q	T
R	U

Activity "V is the last operation of the project and it is also immediate successor to S, T and U. Draw the network of the project.

Answer:

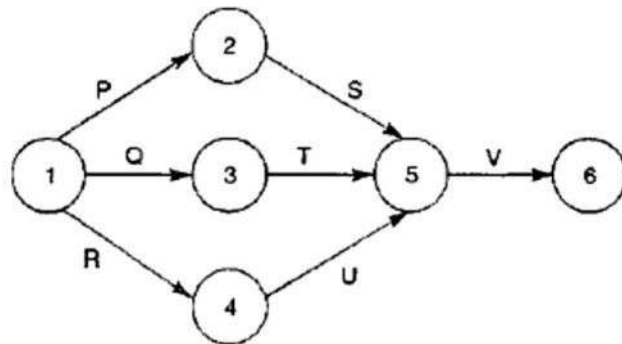


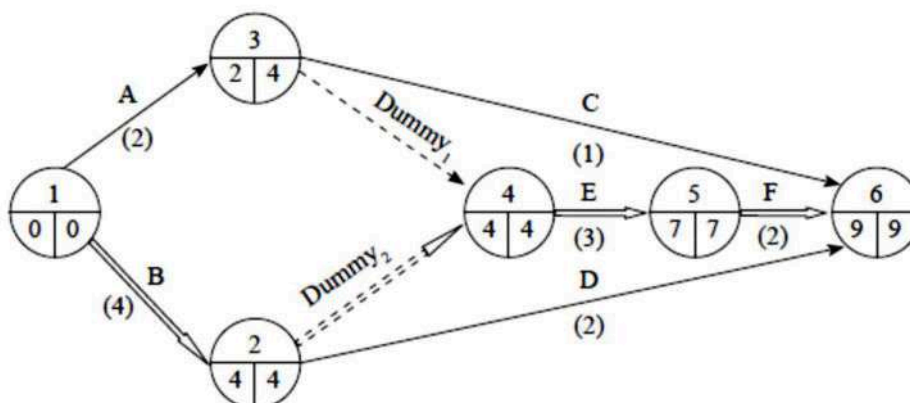
Illustration 2:

Project with the following data is to be implemented. Draw the network and find the critical path.

Activity	Predecessor	Duration (days)	Cost (Rs. Day)
A	-	2	50
B	-	4	50
C	A	1	40
D	B	2	100
E	A,B	3	100
F	E	2	60

- What is the minimum duration of the project?
- Draw a Gantt chart for early start schedule.
- Determine the peak requirement of money and the day on which it occurs in the above schedule.

Answer:





Critical Path

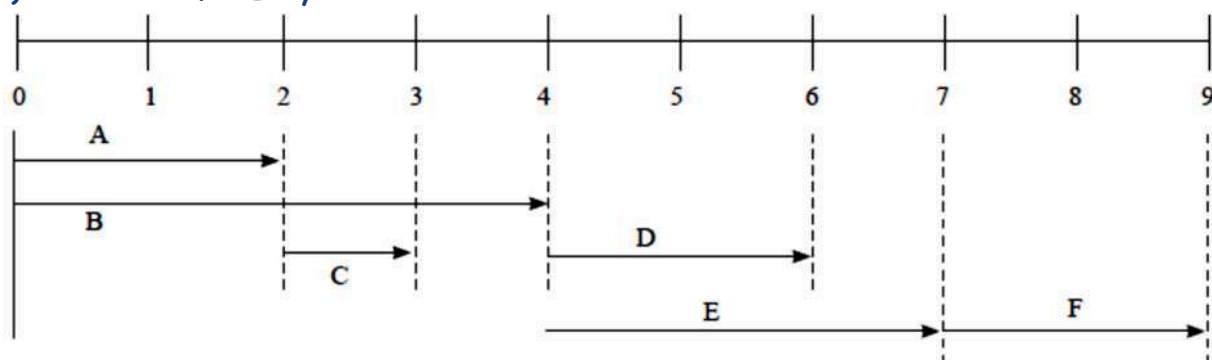
B - Dummy2 - E - F

Minimum duration of the project = 9 days

Table: Activity Relationship

Activity	t	ES (EF-t)	EF	LS (LF-t)	LF	Event Slack (LS-ES) (LF-EF)	On Critical Path
A	2	0	2	2	4	2	No
B	4	0	4	0	4	0	Yes
C	1	4	5	8	9	4	No
D	2	4	6	7	9	3	No
E	3	4	7	4	7	0	Yes
F	2	7	9	7	9	0	Yes

(2) Gantt Chart for Early Start Schedule



(3) Peak requirement of money will occur during simultaneous occurrence of Activities.

From the Network diagram above, it can be said that the following Activities need to occur simultaneously.

(i)	A & B	—	Either during the days 1 & 2 or during the days 3 & 4 of Project Duration, which will require (Rs. 50 for A + Rs. 50 for B) per day i.e. Rs. 100 per day
(ii)	B & C	—	Either on day 3 or on day 4 of the project and it will require (Rs. 50 for B + Rs. 40 for C) per day i.e. Rs. 90 per day
(iii)	C, D & E	—	During day no. 5 or day no. 6 and cost is Rs. (40 + 100 + 100) = Rs. 240 per day
(iv)	C, D & F	—	During day no. 8 or day no. 9 and cost is Rs. (40 + 100 + 60) = Rs. 200 per day
(v)	D & E	—	During day nos. 5 & 6 or 6 & 7. Cost is Rs. (100 + 100) = Rs. 200 per day
(vi)	D & F	—	During day nos. 8 & 9. Cost = Rs. (100 + 60) = Rs. 160 per day
(vii)	C & E	—	Either on day no. 5 or 6 or 7. Cost to be incurred = Rs. (40 + 100) = Rs. 140 per day

From above we can say that C can occur by using either of the options (ii), (iii), (iv) & (vii). As cost for option (ii) is least one should decide for it at a cost of Rs. 90 per day.

Similarly D can occur by either of the option (iii), (iv), (v) & (vi) above. As (vi) is the least cost option of all these, one should go for it at a cost of Rs. 160 per day.

Hence the Project Activities should follow the sequence given below:-

(a) A & B to start at their Earliest Time (i.e 0) and occur simultaneously till day 2 @ Rs. 100 per day

(b) C can start either at its Earliest Time (i.e. 2) or on day 3 and occur simultaneously with B either on day 3 or 4 @ Rs. 90 per day

- (c) E being Critical Activities must have to start at it's earliest time (i.e. 4) and occur @ Rs. 100 per day
- (d) F being Critical Activity has to start on Earliest Time (i.e. 7) and will occur concurrently with D is the during days 8 & 9 @ Rs. 160 per day.
- Hence peak requirement of money is Rs. 160 per day and it will occur at days 8 and 9.

Illustration 3:

A project has the following time schedule

Activity	1-2	1-3	1-4	2-5	3-6	3-7	4-6	5-8	6-9	7-8	8-9
Time (months)	2	2	1	4	8	5	3	1	5	4	3

Construct a PERT network and compute

- Critical path and its duration
- Total float for each activity

Also, find the minimum number of cranes the project must have for its activities 2-5, 3-7, 5-8 and 8-9 without delaying the project given that one crane is sufficient to carry out the work involved in each activity if taken care of individually.

Answer:

Steps:

1. Moving forward, find EF times (choosing the Maximum at activity intersection)
2. Maximum EF = LF = Critical Path Time
3. Return path find LF (Choosing the Minimum at activity intersection)
4. Note LF, EF from network (except activity intersections)

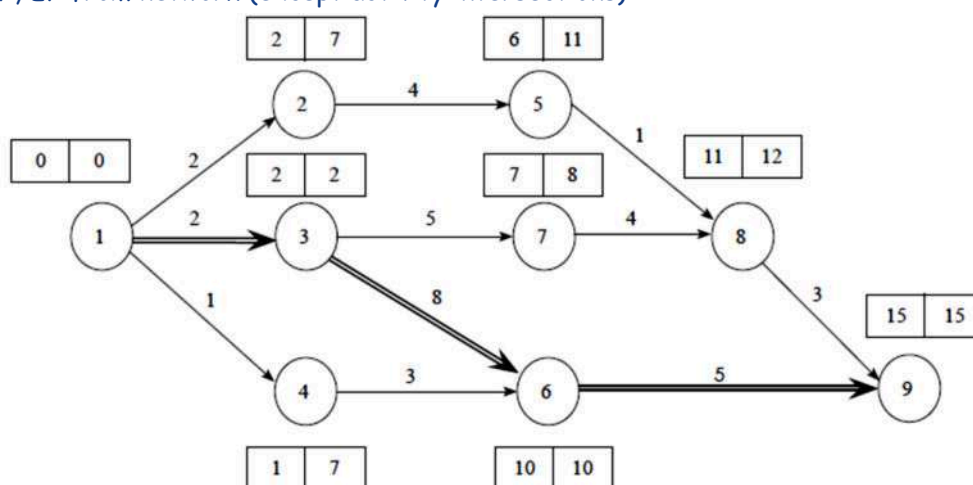


Table: Activity Relationship

Activity	Duration Months (t _{ij})	Earliest Start (ES _{ij})	Earliest Finish (EF _{ij} = ES _{ij} + t _{ij})	Latest Start (LS _{ij} = LF _{ij} - t _{ij})	Latest Finish (LF _{ij})	Total Float (TF _{ij} = LS _{ij} + ES _{ij} = LE _{ij} - EF _{ij})
1-2	2	0	2	5	7	5
1-3	2	0	2	0	2	0
1-4	1	0	1	6	7	6
2-5	4	2	6	7	11	5
3-6	8	2	10	2	10	0
3-7	5	2	7	3	8	1



4-6	3	1	4	7	10	6
5-8	1	6	7	11	12	5
6-9	5	10	15	10	15	0
7-8	4	7	11	8	12	1
8-9	3	11	14	12	15	1

Critical path is 1-3-6-9 with duration 15 months

Minimum number of cranes

- Finish 3 — 7 at its earliest finish time 7 with one crane
- Finish 2 — 5 at its latest finish time $7 + 4 = 11$ with the same crane by starting the activity at its latest start time 7
- Finish 5 — 8 at its latest finish time $11 + 1 = 12$ with the same crane by starting the activity at its latest start time 11
- Finish 8 — 9 at its latest finish time $12 + 3 = 15$ with the same crane by starting the activity at its latest start time 12

Therefore, one crane will be sufficient if start time of the following activities are:

- Activities 2-5 — 7
- Activities 5-8 — 11
- Activities 8-9 — 12

Illustration 4:

A project consists of five activities. Activities P and Q run simultaneously. The relationship among the various activities is as follows:

Activity	Immediate Successor
P	R
Q	S

Activity T is the last operation of the project and it is also immediate successor to R and S. Draw the network of the Project.

Answer:

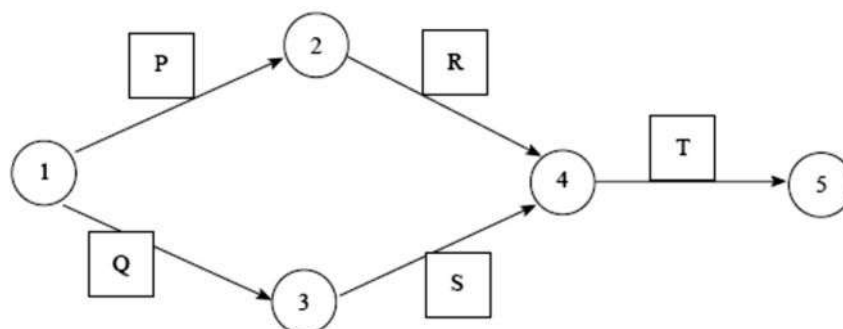


Illustration 5:

XYZ Auto-manufacturing company has to prepare a design of its latest model of motorcycle. The various activities to be performed to prepare design are as follows:

Activity	Description of activity	Preceding activity
A	Prepare drawing	—
B	Carry out cost analysis	A
C	Carry out financial analysis	A
D	Manufacture tools	C

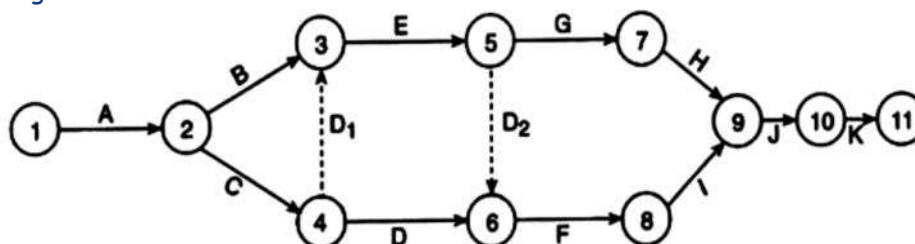


E	Prepare bill of material	B, C
F	Receive material	D, E
G	Order sub-accessories	E
H	Receive sub-accessories	G
I	Manufacture components	F
J	Final assembly	I, H
K	Testing and shipment	J

Prepare an appropriate network diagram.

Answer:

The network diagram will be as follows:



Where D1 and D2 are dummy activities

Illustration 6:

The following table gives data on normal time & cost and crash time & cost for a project.

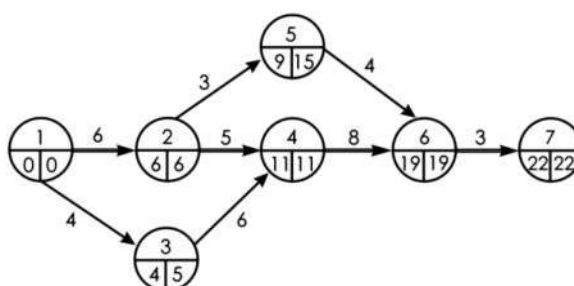
Activity	Normal		Crash	
	Time (days)	Cost (Rs.)	Time (days)	Cost (Rs.)
1-2	6	600	4	1,000
1-3	4	600	2	2,000
2-4	5	500	3	1,500
2-5	3	450	1	650
3-4	6	900	4	2,000
4-6	8	800	4	3,000
5-6	4	400	2	1,000
6-7	3	450	2	800

The indirect cost per day is Rs. 100.

- Draw the network and identify the critical path.
- What are the normal project duration and associated cost?
- Crash the relevant activities systematically and determine the optimum project completion time and cost.

Answer:

- The network for normal activity times indicates a project time of 22 days with the critical path 1-2-4-6-7.



(ii) Normal project duration is 22 days and the associated cost is as follows:

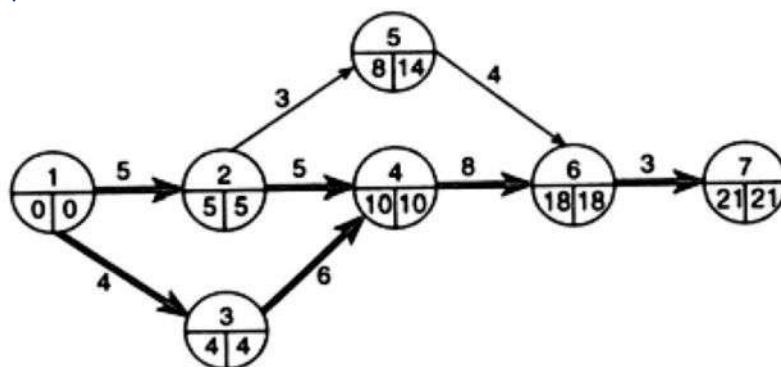
$$\begin{aligned}\text{Total cost} &= \text{Direct normal cost} + \text{Indirect cost for 22 days.} \\ &= 4,700 + 100 \times 22 = \text{Rs. } 6,900.\end{aligned}$$

(iii) For critical activities, cost - slope is given below:

Critical activity	Cost-slope* (Rs./day)	*Cost slope = $\frac{\text{Crash Cost}-\text{Normal Cost}}{\text{Normal Time}-\text{Crash Time}}$
1-2	$\frac{1000 - 600}{6 - 4} = 200$	
2-4	$\frac{1500 - 500}{5 - 3} = 500$	
4-6	$\frac{3000 - 800}{8 - 4} = 550$	
6-7	$\frac{800 - 450}{3 - 2} = 350$	

Of the activities lying on the critical path, activity 1—2 has lowest cost slope. Therefore, we shall first crash this activity by just one day.

$$\text{Duration} = 21 \text{ days, and cost} = 4700 + 1 \times 200 + 100 \times 21 = \text{Rs. } 7000.$$



Other activities too have become critical. Now we have 2 critical paths:

1→2→4→6→7 and 1→3→4→6→7.

To reduce duration of the activity further, we shall have to reduce duration of both the paths. We have following alternatives:

Crash activity 6 — 7 by 1 day at a cost of Rs. 350.

Crash activity 4 — 6 by 4 days at the cost of Rs. 550 per day.

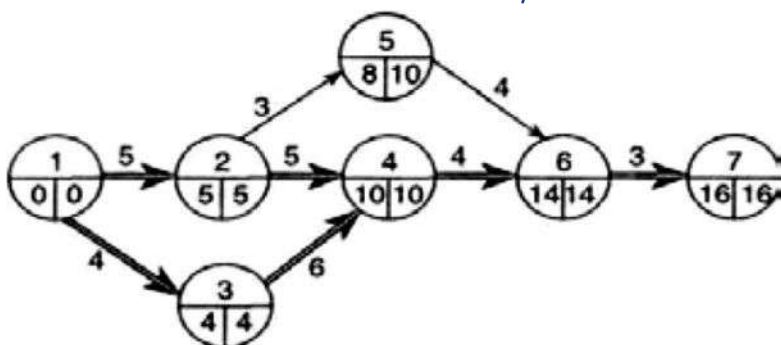
Crash activities 1—2 and 1 — 3 by 1 day each at a cost of Rs. (200 + 700) = Rs. 900.

Crash activities 2 — 4 and 3 — 4 by 2 days each at a cost of Rs. (500 + 550) = Rs. 1050/day.

Thus, we shall first crash activities 6 — 7 by 1 day and then activity 4 — 6 by 4 days.

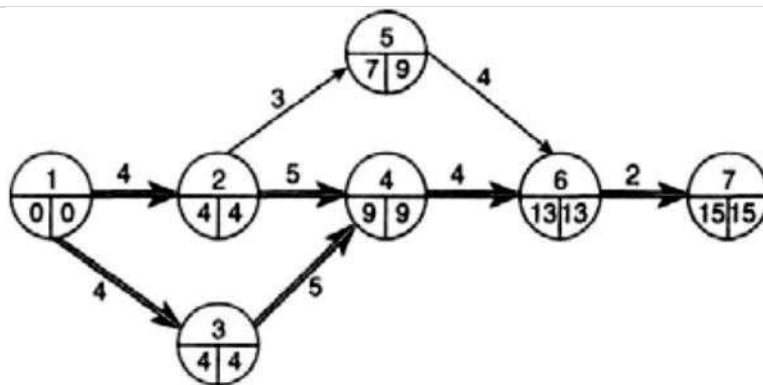
On crashing activity 6 — 7 by 1 day, cost = 4900 + 350 × 1 + 100 × 20 = Rs. 7250, and duration = 20 days. Next we crash 4—6 by 4 days.

$$\text{Cost} = 5250 + 550 \times 4 + 100 \times 16 = \text{Rs. } 9050. \text{ Duration} = 16 \text{ days.}$$



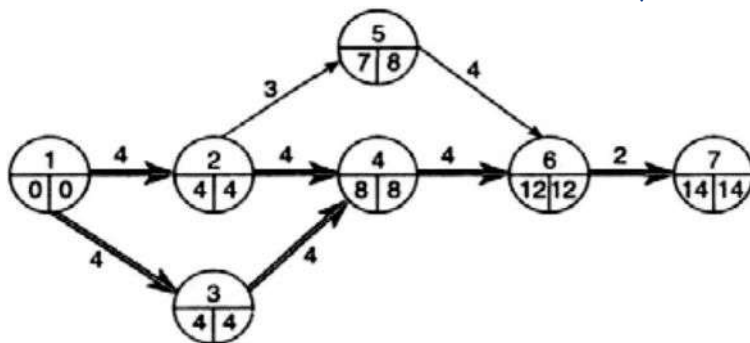
Next we crash activities 1—2 and 3—4 by 1 day each.

$$\text{Cost} = 7450 + 200 \times 1 + 550 \times 1 + 100 \times 15 = \text{Rs. } 9700.$$



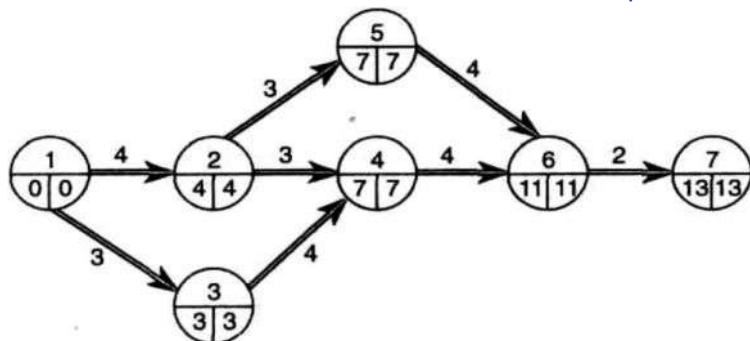
Next we crash activities 2—4 and 3—4 by 1 day each.

Cost = $8200 + 500 \times 1 + 550 \times 1 + 100 \times 14$ = Rs. 10,650. Duration = 14 days.



We crash activities 1—3 and 2—4 by 1 day each.

Cost = $9250 + 700 \times 1 + 500 \times 1 + 100 \times 13$ = Rs. 11,750 Duration = 13 days.



Now there are three critical paths:

1—2—5—6—7, 1—2—4—6—7, 1—3—4—6—7

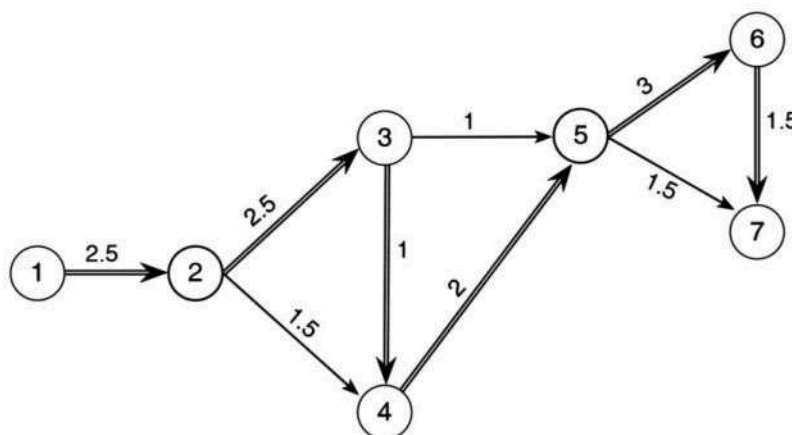
Also, no further crashing is possible. Hence minimum duration of the project =13 days with cost Rs. 11,750

Illustration 7:

Draw the network for the following activities and find critical path and total duration of project.

Activity	Duration (months)	Activity	Duration (months)
1-2	2.5	4-5	2.0
2-3	2.5	5-6	3.0
2-4	1.5	6-7	1.5
3-4	1.0	5-7	1.5
3-5	1.0		

Answer:



Paths	Duration
1-2-3-5-6-7	$2.5+2.5+1+3+1.5 = 10.5$
1-2-3-5-7	$2.5+2.5+1+1.5 = 7.50$
1-2-3-4-5-6-7	$2.5+2.5+1+2+3+1.5 = 12.5$ (Critical path)
1-2-3-4-5-7	$2.5+2.5+1+2+1.5 = 9.5$
1-2-4-5-7	$2.5+1.5+2+1.5 = 7.5$
1-2-4-5-6-7	$2.5+1.5+2+3+1.5 = 10.5$

Illustration 8:

The following activities must be accomplished in order to complete a construction project:

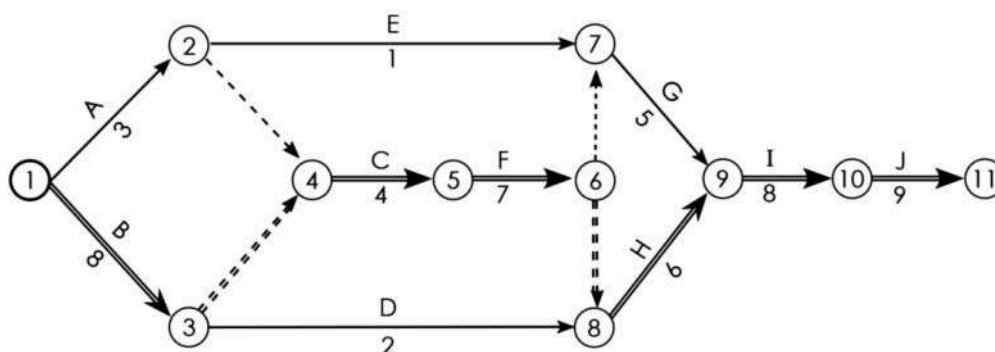
Activity	A	B	C	D	E	F	G	H	I	J
Time	3	8	4	2	1	7	5	6	8	9
Predecessors	—	—	AB	B	A	C	EF	DF	GH	I

- Construct a network diagram for this project. Find the CP and the duration of the project.
- Assume that you are project manager of the project mentioned above. The project has progressed for 10 weeks and the status is follows:

Activities completed: A, B, E. Other activities have not started as yet.

- If no managerial action is taken at all when will the project get completed?
- What action might you take to get the project back to a schedule that can be completed by the end of week 42?

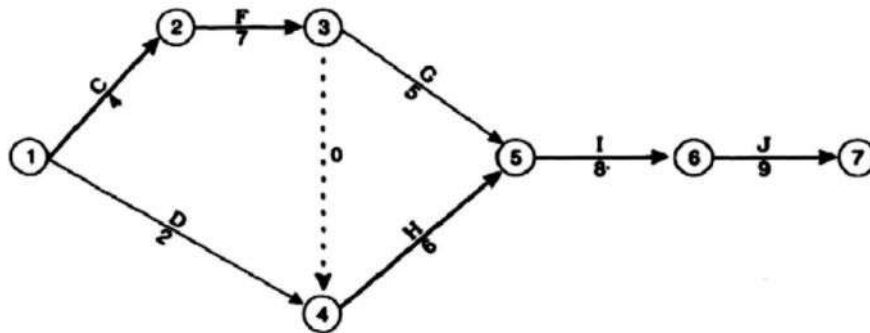
Answer:



Paths	Duration (weeks)	Paths	Duration (weeks)
1-2-7-9-10-11	26	1-3-4-5-6-7-9-10-11	41
1-2-4-5-6-7-9-10-11	36	1-3-4-5-6-8-9-10-11	42
1-2-4-5-6-8-9-10-11	37	1-3-8-9-10-11	33



Critical Path: BCFHIJ. Duration 42 weeks.



Paths	1-2-3-5-6-7	1-2-3-4-5-6-7	1-4-5-6-7
Duration(weeks)	33	34 Critical Path: CFHIJ	25

For completing the project as per original schedule, the project activities on the critical path should be reduced by 2 weeks. For example, we may reduce any one of the activities CFHIJ by 2 weeks or any two activities by one week each.

Illustration 9:

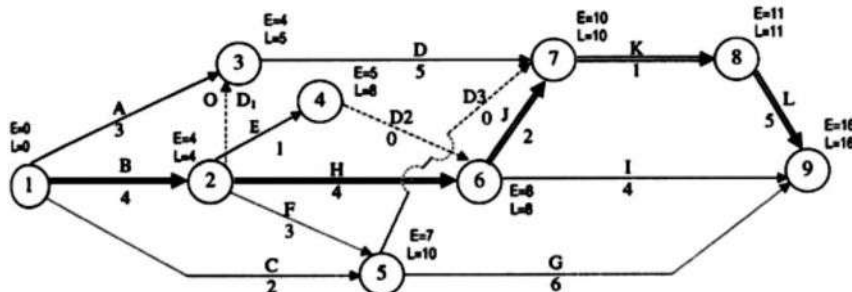
Given is the following information regarding a project:

Activity	A	B	C	D	E	F	G	H	I	J	K	L
Dependence	-	-	-	AB	B	B	FC	B	EH	EH	CDFJ	K
Duration	3	4	2	5	1	3	6	4	4	2	1	5

Draw the Network Diagram and identify the Critical Path and Project Duration.

Answer:

Network Diagram:



Network Table:

Activity	Duration	EST	LST	EFT	LFT	Total Float	Free Float	Independent Float
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A	3	0	2	3	5	2	2 - 1 = 1	1 - 0 = 1
B	4	0	0	4	4	0	0	0
C	2	0	8	2	10	8	8 - 3 = 5	5 - 0 = 5
D1	0	4	5	4	5	1	1 - 1 = 0	0
D	5	4	5	9	10	1	1 - 0 = 1	1 - 1 = 0
E	1	4	7	5	8	3	3 - 3 = 0	0
F	3	4	7	7	10	3	3 - 3 = 0	0
G	6	7	10	13	16	3	3 - 0 = 3	3 - 3 = 0
D2	0	5	8	5	8	3	3 - 0 = 3	3 - 3 = 0
H	4	4	4	8	8	0	0	0
I	4	8	12	12	16	4	4 - 0 = 4	4 - 0 = 4

J	2	8	8	10	10	0	0	0
D3	0	7	10	7	10	3	$3 - 0 = 3$	$3 - 3 = 0$
K	1	10	10	11	11	0	0	0
L	5	11	16	16	16	0	0	0

Critical path is B - H - J - K - L. Expected Duration = 16 days

The columns are updated in the following order as under:

1. Activity (including Dummies) are listed from the Question and network Diagram
2. Duration (including Dummies) are listed from the Question and Network Diagram
3. EST = E value of LHS/ Tail Event from Diagram.
6. LFT = L value of RHS/ Head Event from Diagram.
5. EFT = EST + Duration as per Column (2). Hence Column (5) = Column (3) + Column (2)
4. LST = LFT - Duration as per Column (2). Hence column (4) = Column (6) - Column (2)
7. Total Float = [LET - EFT] or [LST - EST] = [Col.(6) - Col.(5)] or [Col.(4) - Col.(3)]
8. Free Float = Total Float - Head Event Slack i.e. [Col.(7) - difference between L and E of RHS Event].

Note: If Total Float is Zero, Free Float is also equal to Zero. If a negative value is derived, it is restricted to zero.

9. Independent Float = Free Float - Tail Event Slack i.e. [Col (8) - Difference between L and E of LHS Event].

Note: If Free Float is Zero, Independent Float is also equal to Zero. If a negative value is derived, it is restricted to zero.

Note:

- The activities whose Total Float is Zero are Critical Activities. These Total Floats are circled and the respective activities are indicated by double in the network diagram.
- Dummy Activities may or may not lie on the critical path. However, in this question, the dummy activities do not fall on the Critical Path.

Illustration 10:

A project with normal duration and cost along with crash duration and cost for each activity is given below:

Activity	Normal time (Hrs.)	Normal cost (Rs.)	Crash time (Hrs.)	Crash cost (Rs.)
1-2	5	200	4	300
2-3	5	30	5	30
2-4	9	320	7	480
2-5	12	620	10	710
3-5	6	150	5	200
4-5	0	0	0	0
5-6	8	220	6	310
6-7	6	300	5	370

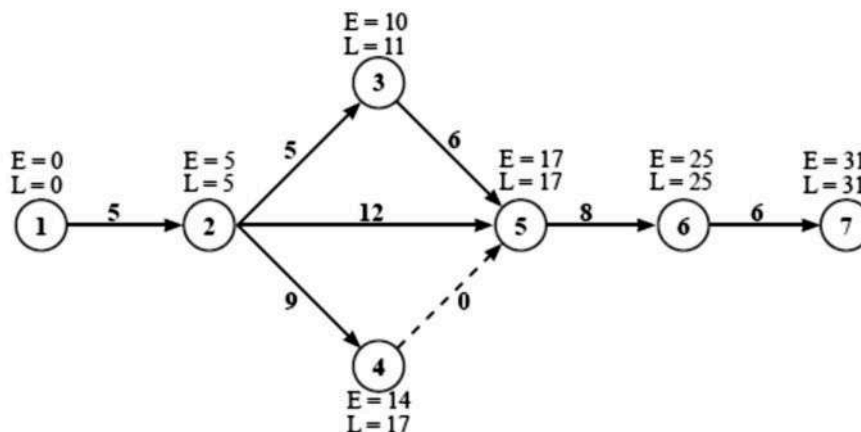
Overhead cost is Rs. 50 per hour.

Required:

Draw network diagram and identify the critical path.



Answer:



Paths →	1-2-5-6-7 (Let's denote this by A)	1-2-3-5-6-7 (Let's denote this by B)	1-2-4-5-6-7 (Let's denote this by C)
Duration	31 hours	30 hours	28 hours
The critical path is A. Its duration is 31 hours			

Illustration 11:

What are the difference between CPM and PERT.

Answer:

CPM originated from construction project while PERT evolved from R & D projects. Both CPM and PERT share the same approach for constructing the project network and for determining the critical path of the network.

There is some basic differences between PERT and CPM

PERT	CPM
1. Time estimate is probabilistic with uncertainty in time duration. Three time estimates.	1. Time estimate is deterministic with known time durations. Single time estimate
2. Event oriented	2. Activity oriented
3. Focused on time	3. Focused on time-cost trade off
4. More suitable for new projects	4. More suited for repetitive projects

Illustration 12:

Construct a network diagram satisfying the following conditions.

$A < D, C$; $B < E$; $D < G, F$; $E, F < H$; $G, H, C < I$

[Hint: $X < Y, Z$ means both Y and Z cannot start until X is complete.]

Answer:

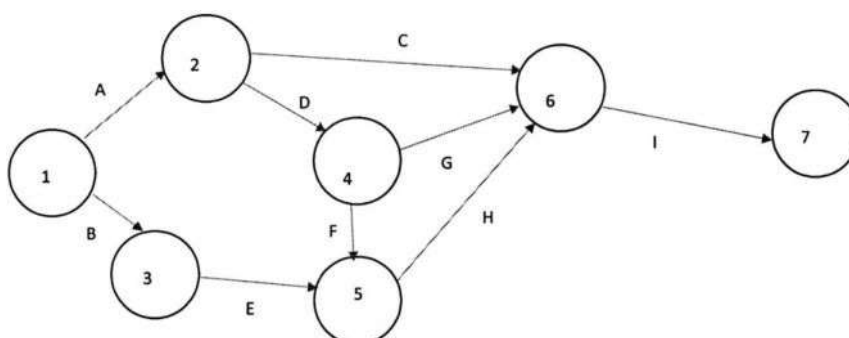


Illustration 13:

Construct the network diagram from the data given below and find

(a) total duration of the project

(b) Critical Path

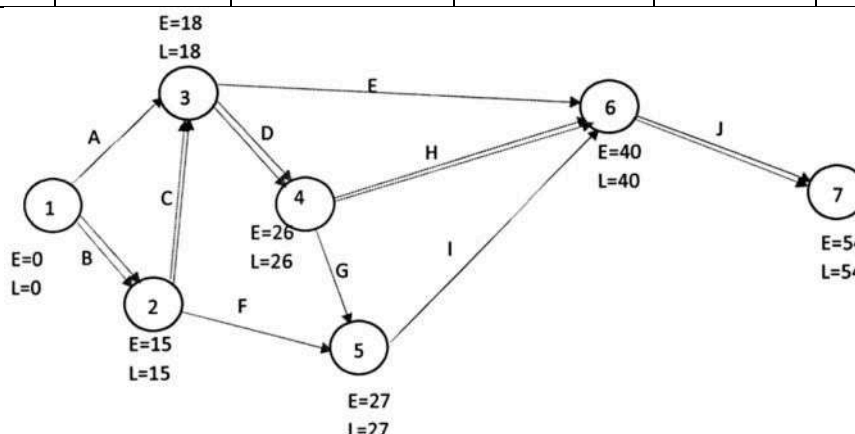
(c) EST, EFT, LST, LFT.

(d) Total float of each activity.

Activity	A	B	C	D	E	F	G	H	I	J
Duration	15	15	3	5	8	12	1	14	3	14
Predecessor Activity	-	-	B	A,C	A	B	D	D	F,G	E,H,I

Answer:

Activity (i-j)	Time (tij)	Earliest Start (ESTij)	Earliest Finish (EFTij = ESTij + tij)	Latest Start (LSTij = LFTij-tij)	Latest Finish (LFTij)	Total Float (TFij = LSTij + ESTij = LETij - EFTij)
A (1-3)	15	0	3	15	18	3
B (1-2)	15	0	0	15	15	0
C (2-3)	3	15	15	18	18	0
D (3-4)	8	18	18	26	26	0
E (3-6)	12	18	28	30	40	10
F (2-5)	5	15	32	20	37	17
G (4-5)	1	26	36	27	37	10
H (4-6)	14	26	26	40	40	0
I (5-6)	3	27	37	30	40	10
J (6-7)	14	40	40	54	54	0



Critical Path 1-2-3-4-6-7

Critical Activity: B -C -D -H-J.

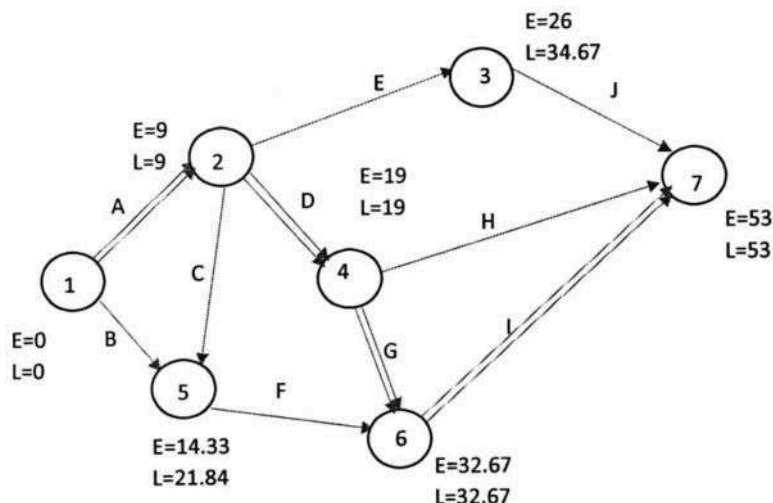
Illustration 14:

For the given data find the expected duration of the project and variance of the project.

Activity	Optimistic time (to)	Most likely Time (tm)	Pessimistic time (tp)
1-2	6	9	12
1-5	4	7	8
2-3	14	17	20
2-4	7	10	13
2-5	3	5	9

3-7	13	18	25
4-6	10	14	16
4-7	12	15	18
5-6	9	11	12
6-7	17	20	25

Answer:



Activity	Optimistic time (to)	Most likely Time (tm)	Pessimistic time (tp)	$\sigma^2 = (tp - to / 6)^2$	$te = to + 4tm + tp / 6$
1-2	6	9	12	1.00	9.0
1-5	4	7	8	0.44	6.7
2-3	14	17	20	1	17.0
2-4	7	10	13	1	10.0
2-5	3	5	9	1	5.33
3-7	13	18	25	4	18.33
4-6	10	14	16	1	13.67
4-7	12	15	18	1	15.00
5-6	9	11	12	0.25	10.83
6-7	17	20	25	1.78	20.33

The critical path is 1 - 2 - 4 - 6 - 7

Variance of the critical path = $1 + 1 + 1.78 = 3.78$

SD of the critical path = SD of the network diagram = $\sqrt{(3.78)} = 1.944$

Illustration 15:

A marketing organization is planning a questionnaire survey on behalf of their client to assess market potential of instant foods. The following activities are involved in this project:

Task	Duration(days)			
	Precedence	Optimistic	Most(likely)	Pessimistic
A. Design Questionnaire		2	3	4
B. Sample design		6	10	20
C. Testing of Questionnaire		2	4	6



and refinements				
D. Recruiting interviewers	B	2	3	10
E. Training of Interviewers	D, A	1	1	1
F. Allocation of Interviewers to territories	B	4	5	6
G. Conducting Interviews	C, E, F	5	12	25
H. Evaluation of results	G	6	10	20

(a) Find the expected duration and variance of each task.

(b) Draw an arrow diagram (network) of the project.

(c) Calculate EST, EFT, LST, LFT & TF

(d) Identify the critical path.

(e) Find the critical path duration of the project.

(f) What percentage of the project will be complete in 44 days?

Activity	A	M	B	Te	Variance	EST	EFT	LST	LFT	TF
A	2	3	4	3	1/9	0	3	12	15	12

(g) Find the no of day by which approximately 100% of the project will be completed

Answer:

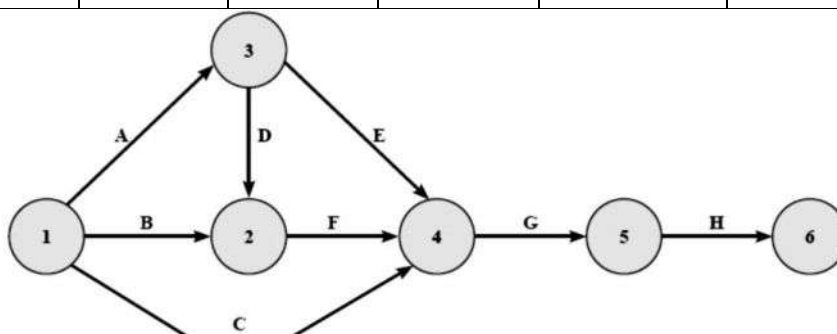
t_e = Expected time

A = Optimistic time;

M = Most likely time;

B = Pessimistic time

Activity	A	M	B	Te	Variance	$t_e = (A + 4M + B) / 6$ $\text{Variance (t)} = [(B-A)]^2$
A	2	3	4	3	1/9	
B	6	10	20	11	49/9	
C	2	4	6	4	4/9	
D	2	3	10	4	16/9	
E	1	1	1	1	0	
F	4	5	6	5	1/9	
G	5	12	25	13	100/9	
H	6	10	20	11	49/9	



Activity	A	M	B	Te	Variance	EST	EFT	LST	LFT	TF
A	2	3	4	3	1/9	0	3	12	15	12

B	6	10	20	11	49/9	0	11	0	11	0
C	2	4	6	4	4/9	0	4	12	16	12
D	2	3	10	4	16/9	11	15	11	15	0
E	1	1	1	1	0	15	16	15	16	0
F	4	5	6	5	1/9	11	16	11	16	0
G	5	12	25	13	100/9	16	29	16	29	0
H	6	10	20	11	49/9	29	40	29	40	0

There are two Critical Path

(i) 1---2---3---4---5---6 = $(11 + 4 + 1 + 13 + 11) = 40$

(ii) 1---2---4---5---6 = $(11 + 5 + 13 + 11) = 40$

As both the critical path suggest for both cases 40 days required to complete the project, so we calculate the

standard deviation of critical path

$$CSD_1 = \sqrt{\frac{49}{9} + \frac{16}{9} + 0 + \frac{100}{9} + \frac{49}{9}} = \frac{14.9}{3} = 4.966 \text{ (Approx.)}$$

$$CSD_2 = \sqrt{\frac{49}{9} + \frac{1}{9} + \frac{100}{9} + \frac{49}{9}} = \frac{14.1}{3} = 4.7 \text{ (Approx.)}$$

Here, CSD_2 performing better than CSD_1 , so we select the 2nd Critical Path.

Then here, $\mu = 40$, $\sigma = 4.7$

Since in 44 day taken then the percentage of work done

$$P(T = 44) = P((T - \mu)/\sigma = ((44 - 40)/4.7))$$

$$P(Z < 4/4.7)$$

$$P(Z < 0.8) = 0.78814$$

Nearly 79% of the project will be completed during 44 days.

For the completion of 100% of the project we can take the 3 sigma limit

$$P(T \leq n)$$

$$P((T - \mu)/\sigma = (n - \mu)/\sigma) = P(Z \leq 3)$$

$$P(Z \leq (n - 40)/4.7) = P(Z \leq 3)$$

$$n = 4.7 \times 3 + 40$$

$$n = 54 \text{ day (Approx)}$$

Illustration 16:

A management institute plans to organize a conference on use of "Operation Research for decision making". In order to co-ordinate the project, it has decided to use a PERT network. The major activities and time estimates for activity has been compiled as follows:

Sl.No.	Activity description	Time estimate (a-m-b)	Activity that must precede
A	Design conference meeting theme	1-2-3	None
B	Design front cover of conference proceedings	1-2-3	A
C	Design brochure	1-2-3	A
D	Compile list of distinguished speakers	2-4-6	A
E	Finalize brochure and print it	2-5-14	C and D
F	Make travel arrangements for distinguished speakers	1-2-3	D



G	Send brochures	1-3-5	E
H	Receive papers for conference	10-12-20	G
I	Edit papers	3-5-7	H
J	Print proceedings	5-10-15	B and I

- Draw the network.
- Calculate expected time for each activity and variance for each activity.
- Calculates EST, EFT, LST, LFT, TF
- Identify critical path.
- Find the no of day by which approximately 90% of the project will be completed

Answer:

t_e = Expected time

A = Optimistic time;

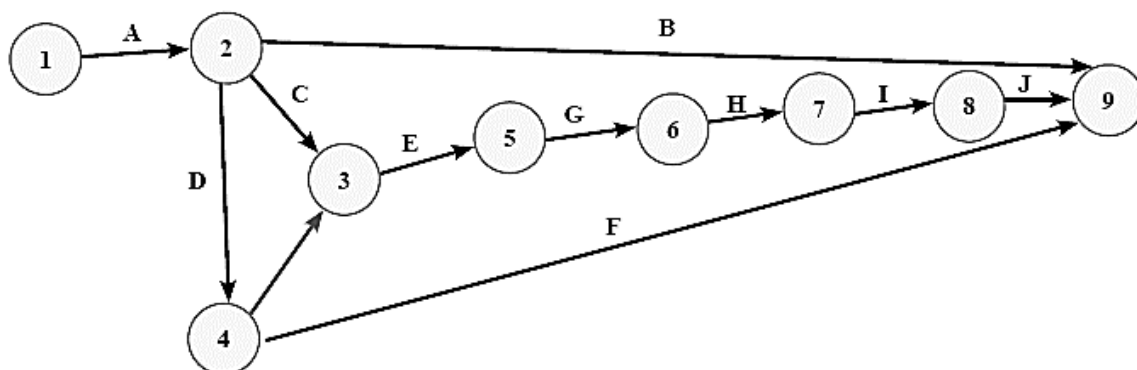
M = Most likely time;

B = Pessimistic time

Activity	A	M	B	t_e	Variance (t)
A	1	2	3	2	1/9
B	1	2	3	2	1/9
C	1	2	3	2	1/9
D	2	4	6	4	4/9
E	2	5	14	6	4
F	1	2	3	2	1/9
G	1	3	5	3	4/9
H	10	12	20	13	25/9
I	3	5	7	5	4/9
J	5	10	15	10	25/9

$$t_e = (A + 4M + B) / 6$$

$$\text{Variance (t)} = [(B - A) / 6]^2$$



Activity	A	M	B	t_e	Variance (t)	EST	EFT	LST	LFT	TF
A	1	2	3	2	1/9	0	2	0	2	0
B	1	2	3	2	1/9	2	4	41	43	39
C	1	2	3	2	1/9	2	4	4	6	2
D	2	4	6	4	4/9	2	6	2	6	0
E	2	5	14	6	4	6	12	6	12	0
F	1	2	3	2	1/9	6	8	41	43	35
G	1	3	5	3	4/9	12	15	12	15	0
H	10	12	20	13	25/9	15	28	15	28	0

I	3	5	7	5	4/9	28	33	28	33	0
J	5	10	15	10	25/9	33	43	10	43	0
Dummy						6	6	6	6	6

Critical Path = 1 - 2 - 4 - 3 - 5 - 6 - 7 - 8 - 9

$$= (2 + 4 + 6 + 3 + 13 + 5 + 10) = 43$$

$$CSD = \sqrt{\frac{1}{9} + \frac{4}{9} + 4 + \frac{4}{9} + \frac{25}{9} + \frac{4}{9} + \frac{25}{9}} = 3.31$$

Let n be the no. of days by which 90% of the project will be completed.

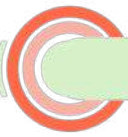
$$P[T \leq n] = 0.90$$

$$P[(T-43)/3.31 \leq (n-43)/3.31] = 0.90 = 1.28$$

$$(n-43)/3.31 = 1.28$$

$$n = (1.28 \times 3.31) + 43$$

$$n = 47.23 = 48 \text{ days}$$



THEORY QUESTIONS

Understanding the fundamental concepts in project management is crucial for successful project execution. Here's a detailed explanation of the basic terminologies with examples and enhanced readability:

Question 1. Distinguish between Activity and Event**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.

Start and Terminal Activities

- **Start Activities:** Activities with no predecessors.
- **Terminal Activities:** Activities with no successors.

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.

Question 2. Explain EFT, EST, LST and LFT**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.

Question 3. Explain EST, EFT, LST and LFT**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:** 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:** 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.

This diagram shows the sequence of activities from Start to End, illustrating concepts like Tail Event, Head Event, and Critical Path.

Essay Questions:

Question 4. How do dummy activities help in project management?

The Role of Dummy Activities in Project Management

Dummy activities play a crucial role in project management, particularly in network diagram techniques like the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). These activities, while not consuming time or resources, serve important purposes in accurately representing project dependencies.

1. Clarifying Dependencies

- **Example:** Suppose Task A and Task B both need to be completed before Task C can begin. A dummy activity can be introduced to connect Task B to Task C, ensuring the sequence is clear and dependencies are properly illustrated.

2. Simplifying Complex Networks

- **Example:** In large construction projects, multiple tasks may overlap or depend on each other in complex ways. Dummy activities help to simplify the representation of these dependencies, making the network easier to understand and manage.

3. Ensuring Accurate Calculations

- **Example:** When calculating critical paths, dummy activities ensure all dependencies are accounted for, leading to precise determination of the project timeline and critical activities. Without dummy activities, some dependencies might be overlooked, resulting in inaccurate project schedules.

4. Enhancing Flexibility

- **Example:** In software development, where tasks are highly interdependent, dummy activities provide the flexibility to adjust the project plan without altering the fundamental dependencies between tasks.

In essence, dummy activities are invisible threads that maintain the integrity of the project network, ensuring all tasks are correctly sequenced and dependencies are fully represented. They are essential tools in the project manager's toolkit, helping to create accurate and manageable project plans.

Question 5. What is the significance of the critical path in project planning?
The Significance of the Critical Path in Project Planning

The critical path is a pivotal concept in project planning, integral to ensuring the timely and successful completion of projects. It represents the sequence of activities that determine the longest path through a project, thus establishing the shortest possible project duration.

1. **Identifying Crucial Tasks** The critical path highlights the tasks that cannot be delayed without impacting the overall project timeline. This allows project managers to prioritize these activities and allocate resources accordingly.
 - **Example:** In building a skyscraper, tasks like laying the foundation, erecting the steel framework, and installing the elevators are on the critical path. Delays in any of these activities would directly affect the project completion date.
2. **Efficient Resource Allocation** Understanding the critical path helps in optimizing resource allocation. Resources can be focused on critical tasks to ensure they are completed on time, thereby keeping the project on schedule.
 - **Example:** In a software development project, coding the core functionalities might be on the critical path. Ensuring that the best developers are working on these tasks can help in meeting deadlines.
3. **Monitoring Progress** The critical path provides a clear roadmap for tracking project progress. By monitoring the completion of critical path activities, project managers can assess whether the project is on track or if corrective actions are needed.
 - **Example:** In an event planning project, securing the venue and arranging the key logistics might be on the critical path. Regular updates on these tasks help ensure the event preparation is progressing as planned.
4. **Risk Management** Identifying the critical path allows project managers to anticipate and mitigate risks. Understanding which tasks are critical helps in developing contingency plans to address potential delays or issues.
 - **Example:** In a product launch project, activities like finalizing the product design and obtaining regulatory approvals are critical. Knowing these tasks are on the critical path allows for proactive risk management, such as expediting approval processes.

In essence, the critical path is crucial for effective project planning and management. It ensures that project managers focus on the tasks that directly impact the project timeline, optimize resource usage, monitor progress efficiently, and manage risks proactively. By understanding and managing the critical path, projects are more likely to be completed on time and within scope.

1. Explain the difference among total float, free float and independent float in project scheduling.
Total Float, Free Float and Independent Float **You**
2. Explain the difference among total float, free float and independent float in project scheduling.
Please write a short essay with examples

Understanding Total Float, Free Float, and Independent Float in Project Scheduling
Question 6. Explain, Total Float, Free Float and Independent Float

In project scheduling, floats are essential concepts that help project managers identify the flexibility of tasks in the project timeline. Here, we explore the differences among total float, free float, and independent float, with relevant examples.

1. Total Float

Definition: Total float is the amount of time an activity can be delayed without affecting the overall project completion date.

Example: Consider a construction project where laying the foundation has a total float of 5 days. This means that laying the foundation can be delayed by up to 5 days without delaying the project's final completion date.

Importance: Total float helps project managers understand which tasks have flexibility in their schedule and how to allocate resources without affecting the overall timeline.

2. Free Float

Definition: Free float is the amount of time an activity can be delayed without affecting the early start of any subsequent activities.

Example: In a software development project, if the task of designing the user interface has a free float of 3 days, it means that this task can be delayed by 3 days without delaying the start of the next task, which might be coding the front-end features.

Importance: Free float is crucial for identifying tasks that can be delayed without impacting other dependent tasks. It provides more localized flexibility within the project schedule.

3. Independent Float

Definition: Independent float is the amount of time an activity can be delayed without affecting the early start of succeeding activities or the late finish of preceding activities.

Example: In an event planning project, if setting up the stage has an independent float of 2 days, it means this task can be delayed by 2 days without affecting the start of the sound check (successor task) or the completion of stage design (predecessor task).

Importance: Independent float offers the most conservative measure of flexibility as it ensures no impact on both preceding and succeeding activities. It provides a buffer that guarantees no disruptions in the overall project flow.

Comparison Chart

Float Type	Impact on	Example
Total Float	Overall Project Completion Date	Laying Foundation in construction project (5days)
Free Float	Early start of subsequent activities	Designing user interface in software project (3 days)
Independent Float	Both Proceeding and Succeeding activities	Setting up stage in event planning Project (2 days)

Question 7. How can the earliest and latest event times impact project timelines?

Impact of Earliest and Latest Event Times on Project Timelines

The earliest and latest event times are fundamental concepts in project scheduling, significantly impacting the overall timeline and successful completion of a project. Understanding these times allows project managers to optimize scheduling, resource allocation, and risk management.

Earliest Event Time (EET)

Definition: The earliest event time is the soonest an event can occur in a project, assuming that all preceding events and activities happen as early as possible.

Impact:

1. **Optimizing Scheduling:** Knowing the earliest start times helps in creating an efficient project schedule. It ensures that tasks commence as soon as possible, reducing idle times and enhancing productivity.
 - **Example:** In a software development project, identifying the earliest start time for coding ensures that developers can begin work immediately after the design phase is completed, maintaining momentum.
2. **Resource Allocation:** With earliest event times, managers can allocate resources more effectively, ensuring that teams and equipment are available when needed.
 - **Example:** In a construction project, knowing the earliest event time for laying the foundation allows managers to ensure that construction workers and machinery are ready and available, preventing delays.
3. **Project Tracking:** Early event times provide milestones that help in tracking project progress and identifying potential delays early on.
 - **Example:** In an event planning project, having an early start time for securing the venue allows the team to address any issues promptly, ensuring that subsequent activities like setting up the stage and arranging logistics proceed smoothly.

Latest Event Time (LET)

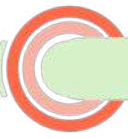
Definition: The latest event time is the latest an event must occur to ensure that the project stays on schedule and meets its completion deadline.

Impact:

1. **Identifying Critical Activities:** The latest event times help in identifying critical activities that must be prioritized to prevent delays.
 - **Example:** In the manufacturing of consumer electronics, knowing the latest time for quality testing helps prioritize this activity to ensure the product launch is not delayed.
2. **Risk Management:** By understanding the latest times, project managers can develop contingency plans for activities that are at risk of running late.
 - **Example:** In a pharmaceutical research project, knowing the latest time for regulatory approval allows for planning alternative steps to expedite the process, reducing the risk of delays.
3. **Balanced Resource Utilization:** Latest event times help in balancing resource utilization, ensuring that resources are not overcommitted and can be diverted to other tasks as needed.
 - **Example:** In a marketing campaign, knowing the latest time for content creation allows the team to focus on other tasks, like social media planning, until they reach the critical timeline for content development.

Conclusion:

In essence, the earliest and latest event times are crucial for effective project management. They provide a structured timeline that ensures tasks are initiated and completed at optimal times, resources are efficiently utilized, and risks are mitigated. By leveraging these times, project managers can maintain control over the project timeline, ensuring successful and timely project completion.



Key Terminologies in PERT (Programme Evaluation Review Technique)

Question 8. Explain Optimistic time, Pessimistic time, most likely time and expected time in PERT Analysis?

In PERT, a probabilistic approach is used for project scheduling and management. Here are some key terminologies with explanations and examples to help you understand:

1. Optimistic Time Estimate (to)

This is the shortest possible time in which an activity can be completed under ideal conditions.

- **Example:** If laying a pipeline could take as little as 4 days under the best conditions, this is the optimistic time estimate.
- **Notation:** to

2. Pessimistic Time Estimate (tp)

This is the maximum time required to complete an activity.

- **Example:** If laying the same pipeline could take up to 10 days in the worst-case scenario, this is the pessimistic time estimate.
- **Notation:** tp

3. Most Likely Time (tm)

This is the time that the activity will most frequently take if performed multiple times.

- **Example:** If typically, laying the pipeline takes 6 days, this is the most likely time estimate.
- **Notation:** tm

4. Expected Time and Standard Deviation

The expected time (Te) and standard deviation provide an estimate for project scheduling.

- **Expected Time (Te):**
 $Te = to + tp + 4tm / 6$
- **Example:** For the pipeline, if to = 2 days, tp = 10 days, and tm = 6 days:
 $Te = 2 + 10 + 4 \times 6 / 6 = 6$ days
- **Standard Deviation:**
 $Standard\ Deviation = \sqrt{\sum (tp - to)^2 / 6}$
- **Example:** For the same pipeline, if tp = 10 days and to = 4 days:
 $Standard\ Deviation = \sqrt{(10 - 4)^2 / 6} = 1$

Question 9. Distinguish between Merge and Burst Event**1. Merge Event**

An event where more than one activity ends.

- **Example:** In a project, if activities A and B both finish at Event 3, Event 3 is a merge event.

2. Burst Event

An event from which more than one activity starts.

- **Example:** In the same project, if activities C and D both start from Event 2, Event 2 is a burst event.

3. Merge and Burst Events

Events where more than one activity ends and more than one activity starts.

- **Example:** If activities E, F end and activities G, H start at Event 4, Event 4 is both a merge and burst event.

Key Terminologies in PERT (Programme Evaluation Review Technique)

In PERT, a probabilistic approach is used for project scheduling and management. Here are some key terminologies with explanations and examples to help you understand:

1. Optimistic Time Estimate (t_o)

This is the shortest possible time in which an activity can be completed under ideal conditions.

- **Example:** If laying a pipeline could take as little as 4 days under the best conditions, this is the optimistic time estimate.
- **Notation:** t_o

2. Pessimistic Time Estimate (t_p)

This is the maximum time required to complete an activity.

- **Example:** If laying the same pipeline could take up to 10 days in the worst-case scenario, this is the pessimistic time estimate.
- **Notation:** t_p

3. Most Likely Time (t_m)

This is the time that the activity will most frequently take if performed multiple times.

- **Example:** If typically, laying the pipeline takes 6 days, this is the most likely time estimate.
- **Notation:** t_m

4. Expected Time and Standard Deviation

The expected time (T_e) and standard deviation provide an estimate for project scheduling.

- **Expected Time (T_e):**

$$T_e = t_o + t_p + 4t_m$$
- **Example:** For the pipeline, if $t_o = 4$ days, $t_p = 10$ days, and $t_m = 6$ days:

$$T_e = 4 + 10 + 4 \times 6 = 6.33 \text{ days}$$
- **Standard Deviation:**

$$\text{Standard Deviation} = \frac{t_p - t_o}{6}$$
- **Example:** For the same pipeline, if $t_p = 10$ days and $t_o = 4$ days:

$$\text{Standard Deviation} = \frac{10 - 4}{6} = 1$$

5. Merge Event

An event where more than one activity ends.

- **Example:** In a project, if activities A and B both finish at Event 3, Event 3 is a merge event.

6. Burst Event

An event from which more than one activity starts.

- **Example:** In the same project, if activities C and D both start from Event 2, Event 2 is a burst event.

7. Merge and Burst Events

Events where more than one activity ends and more than one activity starts.

- **Example:** If activities E, F end and activities G, H start at Event 4, Event 4 is both a merge and burst event.

Short Essay Questions:

Question 10. Explain the significance of the expected time (T_e) in PERT analysis.

The Significance of the Expected Time (T_e) in PERT Analysis

In PERT (Programme Evaluation Review Technique) analysis, the expected time (T_e) is a crucial metric used for project scheduling and management. It provides a realistic estimate of the duration required to complete project activities by accounting for variability and uncertainty in time estimates.

1. Balancing Optimism and Pessimism

- **Definition:** The expected time (T_e) is calculated using three time estimates: optimistic time (t_o), pessimistic time (t_p), and most likely time (t_m).

$$T_e = (t_o + t_p + 4t_m) / 6$$

- **Example:** If constructing a bridge has $t_o = 100$ days, $t_p = 150$ days, and $t_m = 120$ days, the T_e would be:

$$T_e = (100 + 150 + 4 \times 120) / 6 = 123.33 \text{ days}$$

This value considers the best-case, worst-case, and most probable scenarios, providing a balanced estimate.

2. Enhancing Accuracy and Realism

- **Purpose:** The use of T_e ensures that project schedules are neither overly optimistic nor pessimistic. It provides a realistic timeframe that accounts for potential delays and uncertainties, which are inherent in any project.

3. Facilitating Better Decision-Making

- **Example:** In a software development project, using T_e helps managers allocate resources efficiently, plan for contingencies, and set realistic deadlines. This enables more informed decision-making and better risk management.

4. Supporting Critical Path Analysis

- **Impact:** The expected time is pivotal in calculating the critical path, which determines the sequence of activities that dictate the project's minimum completion time. Accurate T_e values ensure that the critical path reflects realistic project timelines.

5. Improving Communication and Expectations

- **Example:** When communicating project timelines to stakeholders, using T_e provides a more credible schedule. Stakeholders are better prepared for potential delays, and expectations are managed effectively.

Conclusion: The significance of T_e in PERT analysis lies in its ability to blend different time estimates into a single, realistic duration. This helps in creating more accurate schedules, improving resource allocation, enhancing decision-making, and managing stakeholder expectations. By incorporating variability, T_e ensures that project plans are robust and adaptable, ultimately contributing to the successful completion of projects.

Question 11. How do optimistic and pessimistic time estimates help in project scheduling?

The Role of Optimistic and Pessimistic Time Estimates in Project Scheduling

In project scheduling, optimistic and pessimistic time estimates play a vital role in planning, risk management, and resource allocation. These estimates provide a range of possible outcomes, helping project managers develop realistic and adaptable schedules.

1. Optimistic Time Estimate (t_o)

Definition: The optimistic time estimate represents the shortest possible duration for an activity, assuming everything goes perfectly and no issues arise.

Example: In a construction project, if laying the foundation could take as little as 5 days under ideal conditions, this is the optimistic time estimate.

Impact on Scheduling:

- **Early Start:** Knowing the best-case scenario helps project managers identify the earliest possible start dates for subsequent tasks.
- **Buffer Planning:** It allows for the creation of buffer zones to absorb potential delays in less critical tasks, thereby protecting the critical path.
- **Optimism in Communication:** Presenting optimistic estimates can help in setting ambitious but achievable goals, motivating teams to perform efficiently.

2. Pessimistic Time Estimate (tp)

Definition: The pessimistic time estimate is the maximum duration an activity might take, considering all possible delays and worst-case scenarios.

Example: If the same foundation-laying task could take up to 10 days due to unforeseen issues like bad weather or equipment failure, this is the pessimistic time estimate.

Impact on Scheduling:

- **Risk Assessment:** Identifying the worst-case scenario helps in anticipating potential risks and developing contingency plans.
- **Realistic Deadlines:** It ensures that project timelines are realistic and achievable, even in adverse conditions.
- **Prioritization:** Highlighting tasks with high pessimistic estimates helps in prioritizing resource allocation to mitigate delays.

3. Combining Estimates for Better Planning

Balanced Scheduling: By considering both optimistic and pessimistic estimates, project managers can strike a balance between ambition and realism. This balanced approach helps in setting achievable milestones and deadlines.

Expected Time Calculation: Using the formula:

$$T_e = (t_o + t_p + 4t_m) / 6$$

managers can determine a weighted average time that considers both extremes, resulting in a more accurate and practical project schedule.

Example: In software development, if writing a code module has an optimistic time of 3 days, a pessimistic time of 9 days, and a most likely time of 5 days, the expected time (T_e) would be:

$$T_e = (3 + 9 + 4 \times 5) / 6 = 5.67 \text{ days}$$

This expected time helps in creating a schedule that is both ambitious and realistic.

Conclusion: Optimistic and pessimistic time estimates are crucial for comprehensive project scheduling. They provide a range of outcomes that help in risk management, realistic planning, and effective resource allocation. By integrating these estimates, project managers can develop robust schedules that accommodate uncertainties, ensuring project success.

Question 12. What is merge and burst events in project networks.

In project management, the concepts of merge and burst events are crucial for understanding the flow and dependencies of tasks within a project network. These events significantly impact how projects are planned, monitored, and controlled.

Merge Events

Definition: A merge event is a point in the project network where multiple activities converge. It signifies the completion of more than one activity leading to a subsequent activity or milestone.

Example: Imagine a software development project where tasks A (designing the user interface) and B (setting up the database) must both be completed before task C (integrating the user interface with the database) can start. The point at which tasks A and B meet to begin task C is a merge event.

Burst Events

Definition: A burst event is a point in the project network from which multiple activities originate. It signifies the start of several tasks from a single preceding activity or milestone.

Example: In the same software development project, once the main software architecture is completed (task D), tasks E (developing the front-end), F (developing the back-end), and G (creating the API) may all start simultaneously. The point at which task D leads to tasks E, F, and G is a burst event.

Conclusion: Merge and burst events are essential components of project networks, providing a clear understanding of task dependencies and project flow. Merge events help coordinate dependencies and manage bottlenecks, while burst events facilitate parallel activities and efficient resource allocation. By effectively managing these events, project managers can ensure that projects progress smoothly and are completed on time.

Question 13. Write a short essay on Gantt Chart

What is a Gantt Chart?

A Gantt chart is a powerful project management tool that visually represents a series of activities over a specified time scale. It helps in planning, scheduling, and tracking project progress. Named after its inventor, Henry L. Gantt, the Gantt chart simplifies complex projects by breaking them down into manageable tasks.

Components of a Gantt Chart

- **Horizontal Axis (Xaxis):**

Represents the time scale, which could be in days, weeks, months, or years, depending on the project duration.

- **Vertical Axis (Yaxis):**

Lists the activities or tasks that need to be performed during the project.

Features of a Gantt Chart

- **Horizontal Bars:** Each task is represented by a horizontal bar. The position and length of the bar indicate the start and completion dates of the activity.
- **Progress Indicators:** Often, Gantt charts include progress bars within each task bar to show the percentage of completion.

Question 14. Distinguish between CPM and PERT

CPM vs PERT – Quick Comparison

Feature	CPM	PERT
Time Estimates	Deterministic	Probabilistic (3 estimates)
Focus	Time & Cost Optimization	Time Uncertainty Management
Application	Repetitive Projects	Research & Development
Critical Path	Based on fixed durations	Based on expected durations

PERT vs CPM

Overview

Both PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are essential tools in project management. They help in planning, scheduling, and controlling complex projects—but differ in approach, application, and analysis.

Comparative Table: PERT vs CPM

Aspect	PERT	CPM
Time Estimates	➤ Uses three time estimates: Optimistic, Pessimistic, Most Likely	➤ Uses single time estimate for each task
Focus	➤ Concerned with events (start/end points of operations)	➤ Concerned with activities (time-consuming project elements)
Project Type	➤ Suitable for non-repetitive projects	➤ Designed for repetitive projects
Statistical	➤ Can be analysed statistically	➤ Cannot be analysed statistically

Analysis		
Time-Cost Relationship	➤ Does not establish time-cost relationship	➤ Establishes time-cost relationship (cost $\propto$ time)
Application Areas	➤ Ideal for research & development, defense, innovation	➤ Widely used in civil construction, manufacturing, maintenance

Key Highlights

PERT:

- Developed by the U.S. Navy in 1958
- Best suited for uncertain environments
- Helps estimate realistic timelines using probability
- Useful when activity durations are not predictable

Example: Designing a new drug involves unpredictable stages—PERT helps estimate time using statistical models.

CPM:

- Focuses on efficiency and cost control
- Best suited for routine, predictable projects
- Helps identify critical activities to avoid delays
- Useful when activity durations are known

Example: Building a highway involves standard tasks like excavation, paving, and inspection—CPM helps optimize time and cost.

Time Estimation in PERT

Three Time Estimates:

- Optimistic Time (t_o): Best-case scenario
- Most Likely Time (t_m): Typical duration
- Pessimistic Time (t_p): Worst-case scenario
-

Question 15. "What is Microsoft Project and how is it useful in managing projects?"

Microsoft Project

Microsoft Project is a project management software developed by Microsoft. It's designed to assist project managers in developing schedules, assigning resources, tracking progress, managing budgets, and analyzing workloads.

Example: An IT project manager might use Microsoft Project to plan a software launch, scheduling tasks, allocating team members, and monitoring progress to ensure deadlines are met

QUESTIONS FROM PYP'S

Question 1.

(Dec 24 7M)

BITZON Ltd., a Chemical Product Manufacturing Company have split their Schedule of Implementation into the following 6 activities and have estimated Time Duration (in weeks) under 3 Scenarios as under:

(Time in Weeks)

Activity and Identification		Optimistic time estimate	Pessimistic time estimate	Most likely time estimate
A	1 - 2	5	11	8
B	1 - 3	18	26	22
C	2 - 4	15	25	20
D	3 - 4	4	12	8
E	4 - 5	8	12	10
F	3 - 5	14	26	20

Required:

- Assess the expected duration (in weeks) for each activity.
- Design the PERT Network Diagram and indicate all paths through it.
- Identify the Critical Path and its Duration (in weeks).
- Analyze and indicate the Total Float and Free Float available on each activity

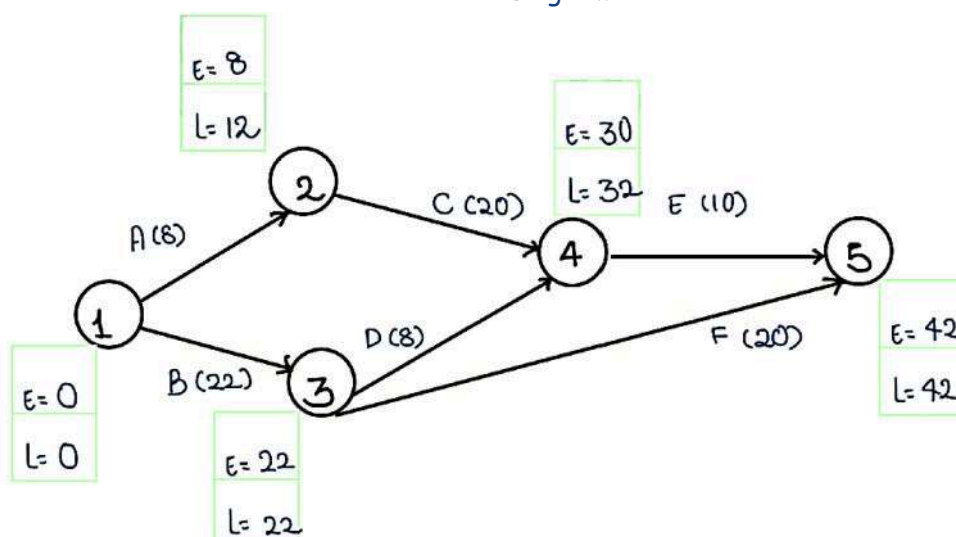
Answer:

(i)

Activity and Identification		Optimistic time estimate (to)	Most likely time Estimate (tm)	Pessimistic time Estimate (tp)	Expected Duration $(to + 4tm + tp)/6$
A	1 - 2	5	8	11	11
B	1 - 3	18	22	26	26
C	2 - 4	15	20	25	25
D	3 - 4	4	8	12	12
E	4 - 5	8	10	12	12
F	3 - 5	14	20	26	26

(ii)

Network Diagram



(iii)

Paths	Duration (in Weeks)
1 - 2 - 4 - 5	$8 + 20 + 10 = 38$ Weeks
1 - 3 - 5	$22 + 20 = 42$ Weeks (Critical Path)
1 - 3 - 4 - 5	$22 + 8 + 10 = 40$ Weeks

Critical path is 1-3-5 (B-F) and project duration is 42 Weeks.

(iv)

Activity	Duration	Slack	EST	EFT	LST	LFT
A (1 - 2)	8	4	0	8	4	12
B (1 - 3)	22	0	0	22	0	22
C (2 - 4)	20	2	8	28	12	32
D (3 - 4)	8	2	22	30	24	32
E (4 - 5)	10	0	30	40	32	42
F (3 - 5)	20	0	22	42	22	42

Activity	Total Float LST - EST or LFT - EFT	Free Float Total Float- Slack Head
A (1 - 2)	4	0
B (1 - 3)	0	0
C (2 - 4)	4	2
D (3 - 4)	2	0
E (4 - 5)	2	2
F (3 - 5)	0	0

Question 2.

(Jun 24 7M)

ZOTECH Ltd., has recently won a Contract for the installation of a die casting machine at a local factory of a large national firm of electronic Engineers. The following table gives the various activities in this job and normal duration (in days) thereof

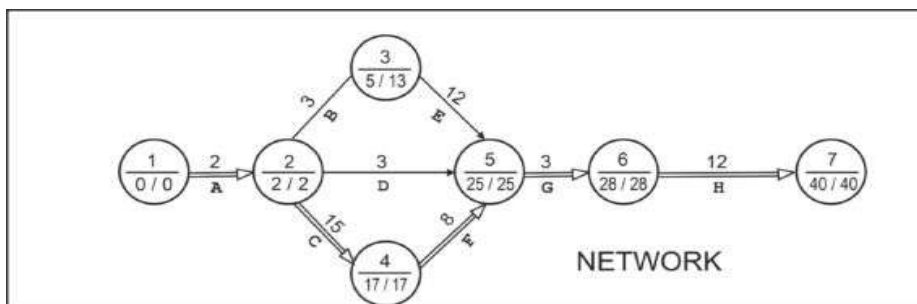
Activity and Identification	Preceding Activities	Duration (days)
A	1-2	-
B	2-3	A
C	2-4	A
D	2-5	A
E	3-5	B
F	4-5	C
G	5-6	D, E, and F
H	6-7	G

Required:

- Design the PERT Network diagram and indicate all paths through it.
- Identify the Critical Path and its duration (in days).
- Analyze and Assess the Total Float, Free Float and Independent Float of each activity

Answer:

(i)



Paths	Duration (in Days)
1-2-3-5-6-7	$2 + 3 + 12 + 3 + 12 = 32$ Days
1-2-5-6-7	$2 + 3 + 3 + 12 = 20$ Days
1-2-4-5-6-7	$2 + 15 + 8 + 3 + 12 = 40$ Days (Critical Path)

Float Calculations:

Activity	Duration	Slack		EST	EFT	LST	LFT
		Tail(L-E)	Head(L-E)				
1-2 (A)	2	0	0	0	2	0	2
2-3 (B)	3	0	8	2	5	10	13
2-4 (C)	15	0	8	2	17	2	17
2-5 (D)	3	0	23	2	5	22	25
3-5 (E)	12	0	17	5	17	13	25
4-5 (F)	8	0	17	17	25	17	25
5-6 (G)	3	0	27	25	28	25	28
6-7 (H)	12	0	28	28	40	28	40

Project Management:

Activity	Total Float	Free Float	Independent Float
1-2 (A)	0	0	0
2-3 (B)	8	0	0
2-4 (C)	0	0	0
2-5 (D)	20	20	20
3-5 (E)	8	8	0
4-5 (F)	10	10	0
5-6 (G)	6	6	0
6-7 (H)	0	0	0

Question 3.

(Dec 23 7M)

TINTEX LTD., a construction company has an opportunity to submit a bid for the construction of anew apartment building. From specifications provided by the developer, a PERT Network for the project has been developed and the estimate of optimistic; most likely and pessimistic, completion duration in days (a ,m and b respectively) for each activity are shown below

Activity and Identification		Optimistic (a)	Most likely (m)	Pessimistic (b)
A	1-2	15	20	20
B	1-3	20	25	25



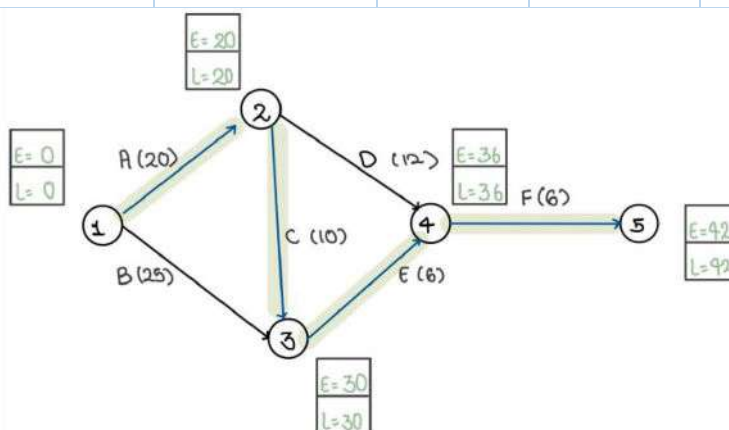
C	2-3	6	10	10
D	2-4	8	12	12
E	3-4	2	6	6
F	4-5	6	10	10

Required:

- Assess the expected Time (in days) of the project.
- Draw the Project Network and identify all paths through it.
- Identify the Critical Path with its duration and assess the Total Float and Free Float of each activity of the Project

Answer:

Activity and Identification		Estimated Time in Days			Expected Time ($t_e = (a + 4m + b) / 6$)
		Optimistic(a)	Most likely(m)	Pessimistic (b)	
A	1-2	15	20	25	20
B	1-3	20	25	3	25
C	2-3	6	10	14	10
D	2-4	8	12	16	12
E	3-4	2	6	10	6
F	4-5	6	10	14	6



Paths	Duration (in Days)
1-2-4-5	$20 + 12 + 6 = 38$ Days
1-2-3-4-5	$20 + 10 + 6 + 6 = 42$ Days (Critical Path)
1-3-4-5	$25 + 6 + 6 = 37$ Days

Critical path is 1-2-3-4-5 (A-C-E-F) and project duration is 42 Days.

Float Calculations:

Activity	Duration	Slack Tail (L-E)	Slack Head (L-E)	EST	EFT	LST	LFT	Total Float (LST-EST or LFT-EFT)	Free Float (Total float - Slack head)
A	20	0	0	0	20	0	20	0	0
B	25	0	0	0	25	5	30	5	0
C	10	0	0	20	30	20	30	0	0
D	12	0	0	20	32	24	36	4	4
E	6	0	0	30	36	30	36	0	0
F	6	0	0	36	42	36	42	0	0

Question 4.
(Dec 23 9M)

HYAAN Ltd., is gearing upto its next big invitational track meet. It has listed the required activities for the same and their required times in days as follows:

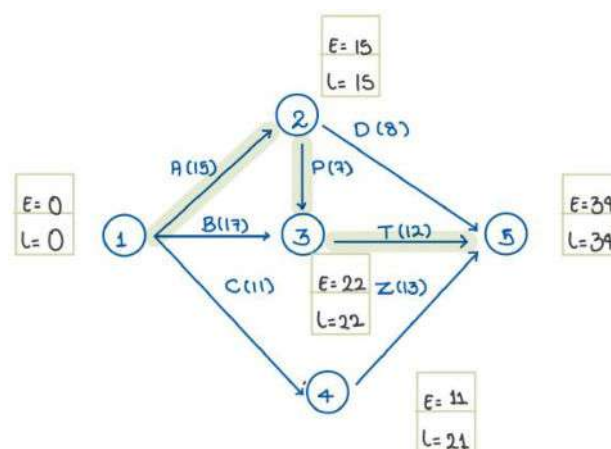
Activities and Identification	A	B	C	D	P	T	Z
	1-2	1-3	1-4	2-5	2-3	3-5	4-5
Preceding	-	-	-	A	A	B & P	C
Planning Time (Days)	15	17	11	8	7	12	13

Required:

- Develop a Network - diagram and identify all the paths through it.
- Identify the critical path and completion time (days)
- Assess the EST, LST, Free Float and Independent Float for all activities of the project

Answer:

(i) Network Diagram



Possible Paths	Workings	Duration
1-2-5	15 + 8	23 Days
1-2-3-5	15 + 7 + 12	34 Days
1-3-5	17 + 12	29 Days
1-4-5	11 + 13	24 Days

Path in 1-2-3-5 is the critical path and total project duration is 34 Days.

Float Calculation:

Activity	Duration	Slack		EST	EFT	LST	LFT	Total Float	Free Float	Independent Float
		Tail (L-E)	Head (L-E)		EST + Durn	LFT - Durn		LST-EST	Total float slack head	Free Float Slack Tail
A	15	0	0	0	15	0	15	0	0	0
B	17	0	0	0	17	5	22	5	5	5
C	11	0	10	0	21	10	21	10	0	0
D	8	0	0	15	23	26	34	11	11	11
P	7	0	0	15	22	15	22	0	0	0
T	12	0	0	22	22	22	34	0	0	0
Z	13	10	0	11	24	21	34	10	10	0

Question 5. (Jun 23 10M)

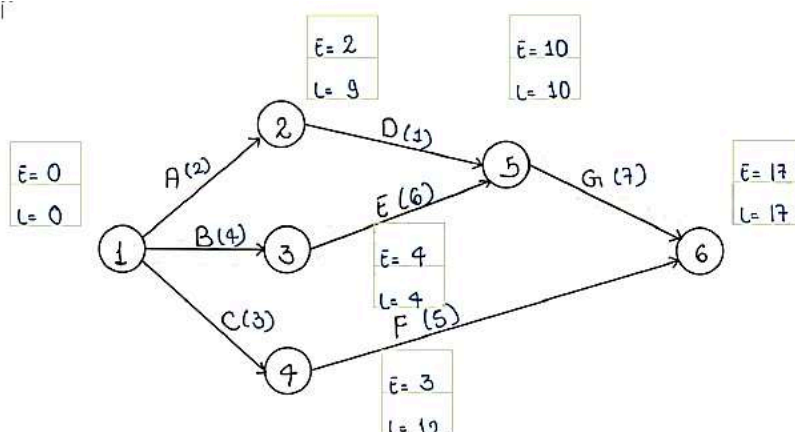
Prantik (P) Ltd., a publisher, is preparing to produce the second edition of a Project Management Text Book. The activities required and their estimated times are as follows:

Activity and Identification		Estimated duration in days		
	1-2	Optimistic	Most Likely	Pessimistic
A	1-3	1	1	7
B	1-4	1	4	7
C	2-5	2	2	8
D	3-5	1	1	1
E	4-6	2	5	14
F	5-6	2	5	8
G	1-2	3	6	15

Required:

- Draw the project network and identify all the paths through it.
- Assess the expected duration and variance for each activity and also project length.
- Identify the critical path and assess the EST, EFT, LST, LFT and total float for each activity

Answer:



Activity	Optimistic Time (to)	Most Likely Time (tm)	Pessimistic Time (tp)	$\sigma^2 = \frac{(tp - to)^2}{6}$	$t_e = \frac{(to + 4tm + tp)}{6}$
A	1	1	7	1	2
B	1	4	7	1	4
C	2	2	8	1	3
D	1	1	1	0	1
E	2	5	14	4	6
F	F	F	F	F	5
G	G	G	G	G	7

Critical path is 1-3-5-6

Variance of the Critical path = 1+4+4 = 9 days

Expected project duration = 4+6+7 = 17 days

Float Calculation:

Activity	Duration	Tail (L-E)	Head (L-E)	Earliest Start Time (EST)	Earliest Finish Time (EFT)
A (1-2)	2	0	7	0	2
B (1-3)	4	0	0	0	4
C (1-4)	3	0	9	0	3
D (2-5)	1	7	0	2	3



E (3-5)	6	0	0	4	10
F (4-6)	5	9	0	3	8
G (5-6)	7	0	0	10	17

Activity	Latest Start Time (LST)	Latest Finish Time (LFT)	Total Float (LST-EST)
A (1-2)	7	9	7
B (1-3)	0	4	0
C (1-4)	9	12	9
D (2-5)	9	10	7
E (3-5)	4	10	0
F (4-6)	12	17	9
G (5-6)	10	17	0

Question 6.
(Jun 23 9M)

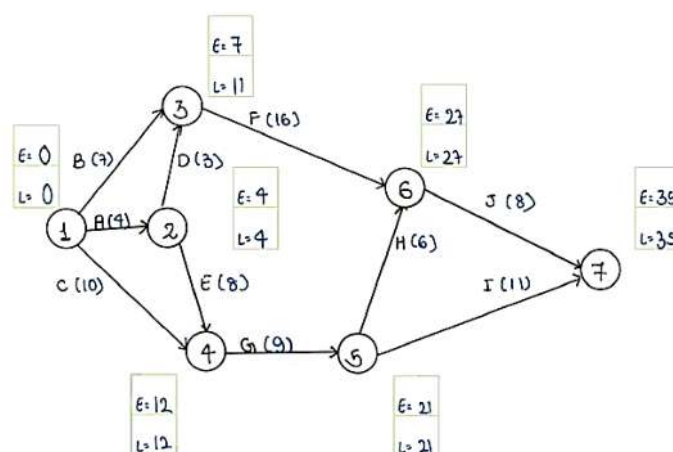
DELTA construction company has an opportunity to submit a bid for the construction of a new apartment building. From specifications provided by the developer, Project Manager of the company has listed down the activities with duration (in days) of the project (construction of apartment building) as a shown below:

Activity Identification		Preceding Activity	Duration (in Days)
A	1-2	-	-
B	1-3	-	-
C	1-4	-	-
D	2-3	A	A
E	2-4	A	A
F	3-6	B and D	B and D
G	4-5	C and E	C and E
H	5-6	G	G
I	5-7	G	G
J	6-7	F & H	F & H

Required:

- Draw the PERT network diagram.
- What are the possible paths with duration of the said project?
- Identify the critical path with duration (in days) of the project.
- Calculate the total float and free float for the activities, C, D, F and I of the said project.

Answer:



Answer:

Possible Paths	Duration
1-3-6-7	$7 + 16 + 8 = 31$ days
1-2-3-6-7	$4 + 3 + 16 + 8 = 31$ days
1-2-4-5-6-7	$4 + 8 + 9 + 6 + 8 = 35$ days (critical path)
1-2-4-5-7	$4 + 8 + 9 + 11 = 32$ days
1-4-5-6-7	$10 + 9 + 6 + 8 = 33$ days
1-4-5-7	$10 + 9 + 11 = 30$ days

Activity	Duration	Slack Head (L-E)	Earliest Start Time EST (ETail)	Latest Start Time (LST)	Latest Finish Time (LFT) (L Head)
C (1-4)	10	0	0	2	12
D (2-3)	3	4	4	8	11
F (3-6)	16	0	7	11	27
I (5-7)	11	0	21	24	35

Activity	Total Float (LST-EST)	Free Float (Total Float - Slack Head)
C (1-4)	2	2
D (2-3)	4	0
F (3-6)	4	4
I (5-7)	3	3

Question 7.

(Dec 22 10M)

AXON TECH Ltd. has recently won a contract for the installation of a die casting machine and its associated building construction work at a local factory of large national firm of electronic engineers. Project manager has listed down the activities in the project as under

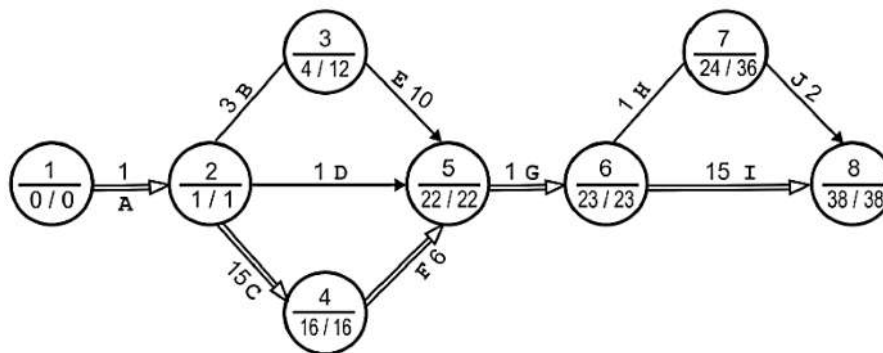
Activity Identification		Preceding Activity	Duration (in Days)
A	1-2	-	-
B	2-3	A	A
C	2-4	A	A
D	2-5	A	A
E	3-5	B	B
F	4-5	C	C
G	5-6	D, E, F	D, E, F
H	6-7	G	G
I	6-8	G	G
J	7-8	H	H

Required:

- Draw the network for the project.
- What are the possible paths with duration of the project?
- Identify the critical path with duration of the project.
- Find Total Float, Free Float and Independent Float of the activities D,E,H and J

Answer:

(i)



Possible Paths	Duration
1-2-3-5-6-7-8	18 Days
1-2-5-6-7-8	6 Days
1-2-5-6-8	18 Days
1-2-4-5-6-7-8	26 Days

Critical Path & Duration:

1-2 - 4-5 - 6-8 and duration is 38 Days

(ii)

Activity	Total Float (Days)	Free Float (Days)	Independent Float (Days)
D	20	20	20
E	8	8	0
H	12	0	0
J	12	12	0

MODULE 7. ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

Questions For Classroom Discussion

Break Down Maintenance or Preventive Maintenance

Question 1

The following data relating to the number of breakdown in a firm for the last 300 days

Number of Breakdown	Frequency
0	40
1	150
2	70
3	30
4	10
Total	300

The firm estimates that each breakdown costs Rs 650 and is considering adopting a preventive maintenance program, which would cost Rs 200 per day and limit the number of break down to an average of one per day.

What is the expected annual saving from preventive maintenance program?

Question 2

The number of breakdowns of an equipment over the past 2 years is given below.

Number of Breakdown	No of Month this Occurred
0	3
1	7
2	9
3	3
4	2
Total	24

Each breakdown cost an average of 300. Preventive maintenance service can be hired at a cost of Rs 150 per month and it will limit the number of breakdowns to an average of one per month.

Which maintenance is preferred?

Preventive or Breakdown?

Obsolescence and Replacement

$$T(n) = C - S + \sum m$$

$$A(n) = \frac{[C - S + \sum m]}{n}$$

Question 3

A firm is using a machine whose purchase price is Rs.13,000. The installation charges amount to Rs.3,600 and the machine has a scrap value of only Rs.1,600 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	Cost
1	250

2	750
3	1000
4	1500
5	2100
6	2900
7	4000
8	4800
9	6000

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.

Question 4

The Simple Engineering Company has a machine whose purchase price is Rs 80,000. The expected maintenance costs and resale price in different years are as given here:

Year	Maintenance Cost	Re Sale Price
1	1000	75000
2	1200	72000
3	1600	70000
4	2400	65000
5	3000	58000
6	3900	50000
7	5000	45000

After what time interval, in your opinion, should the machine be replaced?

Question 5

A machine M1, costing Rs.9,000 has a maintenance cost of Rs.200 in the first year of its operation which rises by Rs.2,000 in each of the successive years.

Assuming that the machine replacement can be done only at the end of a year, determine the best age at which the machine be replaced.

Group Replacement

Question 6

A company has 50 identical machines in its facilities. The cost of preventive servicing (CP) is Rs 20, and the cost of repair after breakdown (CR) is Rs 100. The company seeks the minimum cost preventive servicing frequency and has collected the data on breakdown probabilities in the following table:

Months after Servicing that Breakdown	Probability that Breakdown will occur	Expected Number
1	0.10	
2	0.05	
3	0.05	
4	0.10	
5	0.15	
6	0.15	
7	0.20	

8	0.20	
		5.40

Question 7 Home Work - Previous Year Question (2+2+5 =9 Marks)

The Management of Green in , Hotel is considering the periodic replacement of light bulbs fitted in its rooms. There are 500 rooms in the hotel and each room has 6 bulbs. The management of Green in hotel is now following the policy of replacing bulbs as they fails at a cost of RS 30 per bulb. The management feels that this cost can be reduced to Rs 10 by adopting periodic replacement method ?

The following mortality rate has been observed for the said light bulbs.

Assume that the bulbs that fails during the month are replaced just before the end of that month.

Months of Use	1	2	3	4	5
Probability bulbs failing by the end of the month	0.10	0.15	0.25	0.30	0.20

Required:

- 1) Compute the costs of (in Rs) of Individual Replacement of Bulbs per month
- 2) Present the optimum Replacement cycle under Group Replacement
- 3) State the best strategy for the management of Green Hills to follow
(Present Calculation to the nearest integer)

Independent Problems

Question 8

Indian Electronics, manufactures TV sets, carries out the picture tube testing for 2000 hours.

A sample of 100 tubes was put through this quality test during which two tubes failed.

- 1) If the average usage of TV by the customer is 4 hours/day and if 10,000 TV sets were sold, then in one year how many tubes were expected to fail and
- 2) What is the mean time between failures for these tubes?

Question 9

The main shaft of an equipment has a very high reliability of 0.990.

The equipment comes from Russia and has a high downtime cost associated with the failure of this shaft. This is estimated at Rs.20,000,000 as the costs of sales lost and other relevant costs. However, this spare is quoted at Rs.1,000,000 at present.

Should the shaft spare be procured along with the equipment and kept or not?

Question 10

Product A has a Mean Time Between Failures (MTBF) of 30 hours and has a Mean Time To Repairs (MTTR) of 5 hours. Product B has a MTBF of 40 hours and has a MTTR of 2 hours.

- Q.1 Which product has the higher reliability?
- Q.2 Which product has greater maintainability?
- Q.3 Which product has greater availability ?

Illustration From Study Material

Illustration 1:

M/s Nirmala Toolkit Pvt. Ltd. has a workshop comprising of 20 tool machines of similar type. To improve the preventive maintenance plan, the workshop manager collects the data of failure history of the machines as under

Elapsed time after Maintenance attention (in month)	Probability of failure
1	0.20
2	0.15
3	0.15
4	0.15
5	0.15
6	0.20

It costs Rs. 150 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines.

Answer:

Expected time before failure.

$$= 0.20 \times 1 + 0.15 \times 2 + 0.15 \times 3 + 0.15 \times 4 + 0.15 \times 5 + 0.20 \times 6 = 3.5 \text{ months}$$

Therefore number of repair/machine/annum = $12/3.5$

Considering 20 machines and Rs. 150 to attend a failed machine the yearly cost of servicing
 $= 12/3.5 \times 20 \times 150 = \text{Rs. } 10286.$

Illustration 2:

A Public transport system is experiencing the following number of breakdowns for months over the past 2 years in their new fleet of vehicles:

Number of breakdowns	0	1	2	3	4
Number of months this occurred	2	8	10	3	1

Each break down costs the firm an average of Rs. 2,800. For a cost of Rs. 1,500 per month, preventive maintenance can be carried out to limit the breakdowns to an average of one per month. Which policy is suitable for the firm?

Answer:

Converting the frequencies to a probability distribution and determining the expected cost/month of breakdowns we get:

No. of breakdowns (x)	Frequency in months (f)	Probability ($p = f/\Sigma f$)	Expected no. of breakdowns (px)
0	2	0.083	0.000
1	8	0.333	0.333
2	10	0.417	0.834
3	3	0.125	0.375
4	1	0.042	0.168
	$\Sigma f = 24$	$\Sigma p = 1$	Total 1.710 = Σpx

Expected Breakdown cost per month; Expected no. of breakdowns per month $\times$ cost of each breakdown
 $= 1.710 \times \text{Rs. } 2800 = \text{Rs. } 4788.$

Preventive maintenance cost per month: -

Average cost of one breakdown/month = Rs. 2, 800

Maintenance contract cost/month = Rs. 1,500

Total = Rs. 4,300

Thus, preventive maintenance policy is suitable for the firm.

Illustration 3:

Indian Electronics, manufactures TV sets and carries out the picture tube testing for 2000 hours. A sample of 100 tubes was put through this quality test during which two tubes failed. If the average usage of TV by the customer is 4 hours/day and if 10,000 TV sets were sold, then in one year how many tubes were expected to fail and what is the mean time between failures for these tubes?

Answer:

The total test time = (100 tubes) × 2000 hours = 200,000 tube-hours.

There are two tubes which have failed and hence the total time is to be adjusted for the number of hours lost due to the failures during the testing.

The lost hours are computed as = $2 \times 2000 / 2 = 2000$ hours.

The assumption is made here is that each of the failed tubes have lasted an average of half of the test period. Therefore, the test shows that there are two failures during $(2,00,000 - 2000) = 1,98,000$ tube hours of testing. During 365 days a year (four hours a day) for 10,000 tubes the number of expected failures

$$\frac{1,98,000}{2} \times 10,000 \times 365 \times 4 = 147.47 = 148 \text{ tubes approximately.}$$

$$\text{Mean time between failures} = \frac{1,98,000 \text{ tubes hrs. of testing}}{2 \text{ failure}}$$

$$= 99,000 \text{ tubes hours per failure} = \frac{99,000}{4 \times 365} = 67.8 \text{ tubes year per failure}$$

Illustration 4:

M/s XYZ Pvt. Ltd has 50 identical machines in its facilities. The company has the recorded figure for cost of preventive maintenance (Cp) and cost of breakdown maintenance (Cb) as Rs. 20 and Rs. 100 respectively. The company wants to reduce the breakdown occurrence while minimizing Cp. Given is the data on breakdown occurrence.

Probabilities of machine breakdown, by month:

Months after servicing that breakdown occurs (i)	Probability that breakdown will occur (Pi)	i.P _i
1	0.10	0.10
2	0.05	0.10
3	0.05	0.15
4	0.10	0.40
5	0.15	0.75
6	0.15	0.90
7	0.20	1.40
8	0.20	1.60
Total	1.00	5.40

Answer:

The mean time before failure is 5.4 months and the expected cost with no preventive maintenance would be $100 \times 50 / 5.4 = \text{Rs. } 925.93$ per month. The following calculations show B_j, the expected

number of breakdowns between preventive maintenance intervals, for the possible intervals, that may be considered.

$$B_1 = MP1 = 50 (0.10) = 5$$

$$B_2 = m (P_1 + P_2) + B_1P_1 = 50(0.10+0.05) + 5(0.10) = 8$$

$$B_3 = 50 (0.10 + 0.05 + 0.05) + 8 (0.10) + 5 (0.05) = 11.05$$

$$\text{Accordingly, } B_4 = 16.75, B_5 = 25.63, B_6 = 35.5, B_7 = 48.72, B_8 = 63.46.$$

The costs of various preventive maintenance intervals are summarised in the table below :

Cost of alternative preventive maintenance intervals -

Number of months between preventive services (j)	B _j Expected Number of Breakdown in j months	Expected cost/month to Repair Breakdown CR×B _j /j	Cost per month for preventive service every j month CR(M)/j	Total expected cost per month of preventive maintenance and repair
(1)	(2)	(3)	(4)	(5)
1	5.00	500.00	1000.00	1500.00
2	8.00	400.00	500.00	900.00
3	11.05	368.33	333.33	701.66
4	16.75	418.75	250.00	668.75
5	25.63	512.60	200.00	712.60
6	35.50	591.67	166.67	758.34
7	48.72	696.00	142.86	838.86
8	63.46	793.25	125.00	918.25

A policy of performing preventive maintenance every 4 months results in the lowest average cost, about Rs. 669.

This amount is Rs. 257 per month less than the Rs. 926 expected cost without preventive maintenance. This policy would reduce the costs by $(257 \div 926) \times 100 = 27.75\%$ below the cost of repairing the machines only when they breakdown.

Illustration 5:

Assume the following three breakdown probability distribution

Month following Maintenance	Probability of Breakdown		
	(1)	(2)	(3)
1	0.5	0.1	0.1
2	0.1	0.1	0.1
3	0.1	0.1	0.5
4	0.1	0.1	0.1
5	0.1	0.2	0.1
6	0.1	0.4	0.1

Which, if any, of these distributions lend themselves to a preventive maintenance program? Why?

Answer:

Policy 1:

Month following Maintenance (i)	Probability of Breakdown (p)	Average free run time (i * p)
1	0.5	0.5

2	0.1	0.2
3	0.1	0.3
4	0.1	0.4
5	0.1	0.5
6	0.1	0.6
		$\Sigma 2.5 \text{ months/breakdown/machine}$

Therefore the average number of breakdowns for the pool of say 100 machines per month will be:

For 1 machine in 2.5 months 1 breakdown

So for 1 machine in 1 month ($1/2.5$) breakdown

So for 100 machines in 1 month ($100/2.5$) = 40 breakdowns

Policy 2:

Month following Maintenance (i)	Probability of Breakdown (p)	Average free run time ($i * p$)
1	0.1	0.1
2	0.1	0.2
3	0.1	0.3
4	0.1	0.4
5	0.2	1.0
6	0.4	2.4
		$\Sigma 4.4 \text{ months/breakdown/machine}$

Therefore the average number of breakdowns for the pool of say 100 machines per month will be:

For 1 machine in 4.4 months 1 breakdown

So for 1 machine in 1 month ($1/4.4$) breakdown

So for 100 machines in 1 month ($100/4.4$) = 22.73 breakdowns

Policy 3:

Month following Maintenance (i)	Probability of Breakdown (p)	Average free run time ($i * p$)
1	0.1	0.1
2	0.1	0.2
3	0.5	1.5
4	0.1	0.4
5	0.1	0.5
6	0.1	0.6
		$\Sigma 3.3 \text{ months/breakdown/machine}$

Therefore the average number of breakdowns for the pool of say 100 machines per month will be:

For 1 machine in 3.3 months 1 breakdown

So for 1 machine in 1 month ($1/3.3$) breakdown

So for 100 machines in 1 month ($100/3.3$) = 30.30 breakdowns

Preventive maintenance programs are generally applicable to breakdown distributions with low variability. Policy 2 has the lowest variability as no of breakdowns in a month for a pool of say 100 machines are 22.73---the lowest among three policies.

Therefore we may conclude that policy 2 could lead to a preventive maintenance program.



Illustration 6:

Assume the following three breakdown probability distribution

Month following Maintenance	Probability of Breakdown
1	0
2	0.1
3	0.1
4	0.1
5	0.2
6	0.5

Let us take Average Repair Cost on breakdown C_R = Rs.100 & Cost of Preventive maintenance C_{PM} = Rs.75, Cost of Individual Replacement CI = Rs.80, Cost of Group Replacement = Rs.50 / machine
For a pool of 100 machines, Could you recommend PM? When will you go for Replacement?

Answer

Month following Maintenance (i)	Probability of Breakdown (p)	Average free run time (i * p)
1	0.0	0.0
2	0.1	0.2
3	0.1	0.3
4	0.1	0.4
5	0.2	1.0
6	0.5	3.0
		Σ4.9 months/breakdown/machine

Therefore the average number of breakdowns for the pool of say 100 machines per month will be:

For 1 machine in 4.9 months 1 breakdown

So for 1 machine in 1 month (1/4.9) breakdown

So for 100 machines in 1 month (100/4.9) = 20.40816 breakdowns

Repair Policy Cost = Average number of repairs per month × Average repair cost on breakdown

= 20.40816 × 100 = Rs.2,040.816

Preventive Maintenance Costs for the Six Preventive Maintenance Cycles:

Table-I

Preventive Maintenance Cycle (n) , months	Expected Breakdowns in PM Cycle	Average No of Breakdowns per month (Col.2/ Col.1)	Expected Monthly Breakdown Cost (Col.3 × Rs.100)	Expected Monthly PM Cost (Rs.75 × 100)/ Col.1	Expected Monthly Cost of each PM cycle (Col.4 + Col.5)
1	0	0	0.00	7500	7500.00
2	10	5	500.00	3750	4250.00
3	20	6.667	666.70	2500	3166.70
4	31	7.75	775.00	1875	2650.00
5	53	10.6	1060.00	1500	2560.00
6	106.1	17.683	1768.30	1250	3018.30

Computation of Col. 2:

Month 1: 100*0.0 = 0

Month 2: 100*(0.0+0.1) +0*0.0 = 10



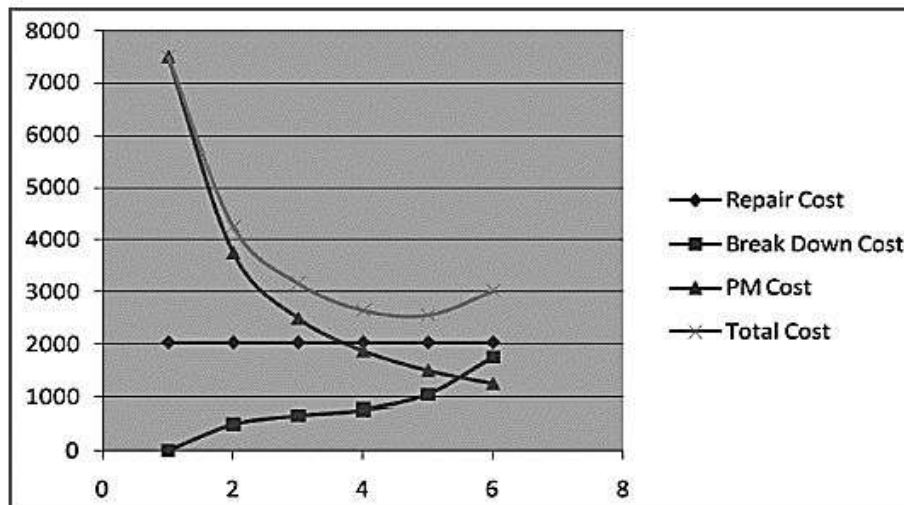
Month 3: $100 \times (0.0 + 0.1 + 0.1) + 0 \times 0.1 + 10 \times 0.0 = 20$

Month 4: $100 \times (0.0 + 0.1 + 0.1 + 0.1) + 0 \times 0.1 + 10 \times 0.1 + 20 \times 0.0 = 31$

Month 5: $100 \times (0.0 + 0.1 + 0.1 + 0.1 + 0.2) + 0 \times 0.1 + 10 \times 0.1 + 20 \times 0.1 + 31 \times 0.0 = 53$

Month 6: $100 \times (0.0 + 0.1 + 0.1 + 0.1 + 0.2 + 0.5) + 0 \times 0.2 + 10 \times 0.1 + 20 \times 0.1 + 31 \times 0.1 + 53 \times 0.0 = 106.1$

Graphical Representation Policy 1:



So from the above it is clearly observed that PM policy is inferior to Repair policy. But will repair policy sustainable?

Answer is NO. After continuing for some time with repair policy cost effectiveness of the policy will be lost and at this stage we have to replace ---either individual machines or in blocks.

To do this analysis we will follow the steps below mentioned:

Step-I: Determination of Number of failures in different weeks.

Table-II

Preventive Maintenance Cycle (n), months	Probability of Breakdown (p)	Expected Breakdowns in PM Cycle
1	0.0	0
2	0.1	10
3	0.1	20
4	0.1	31
5	0.2	53
6	0.5	106.1

Column 2 of Table 1

Step-2: Determination of Average Cost of Different Policies

Table-III

Months	No of Individual Replacements	Cost of Replacements			
		Individual (Col2 × 80)	Group (100 × 50)	Total (Col3 + Col4)	Average Cost (Col5/Col1)
1	0	0	5000	5000	5000
2	10	800	5000	5800	2900
3	20	1600	5000	6600	2200
4	31	2480	5000	7480	1870
5	53	4240	5000	9240	1848
6	106.1	8488	5000	13488	2248

From the table it is observed that the minimum cost per month is obtained by replacing all the

machines (whether failed or not) after every 5 months. Thus optimal replacement time interval = 5 months.

But we can go for a policy "Replace as and when a machine fail" and in that case there will not be any group replacement.

To check the feasibility of "Replace as and when a machine fails" the computation will be as following:

Life (months)	Mean value (Xi)	Probability (pi)	pi x Xi
0-1	0.5	0.0	0
1-2	1.5	0.1	0.15
2-3	2.5	0.1	0.25
3-4	3.5	0.1	0.35
4-5	4.5	0.2	0.9
5-6	5.5	0.5	2.75
			4.4

Mean life of a machine is = 4.4

Expected no of failures of a machine during a week = No of Machines/ Mean life of a machine
 $= 100/4.4 = 22.727$

Weekly replacement cost = Expected no of replacements X cost of replacements
 $= 22.727 \times 80$
 $= 1818.16$

Since the cost of the policy of individual replacement i.e. "Replace as and when a machine fail" is less than that of the group replacement, it is advisable to go for individual replacement.

Illustration 7:

Refer Illustraton No. 5. Let us take Average Repair Cost on breakdown CR = Rs.90 & Cost of Preventive maintenance CPM = Rs.30

Could you prove your conclusion given in A1 for a pool of 100 machines?

Answer:

Repair Policy Cost of Policy 1 = Average number of repairs per month $\times$ Average repair cost on breakdown = $40 \times 90 = \text{Rs.}3,600$.

Data taken from Solution 5.

Preventive Maintenance Costs for the Six Preventive Maintenance Cycles:

Table-I

Preventive Maintenance Cycle (n), months	Expected Breakdowns in PM Cycle	Average No of Breakdowns per month (Col.2/ Col.1)	Expected Monthly Breakdown Cost (Col.3 $\times$ Rs.90)	Expected Monthly PM Cost (Rs.30 $\times$ 100)/ Col.1	Expected Monthly Cost of each PM cycle (Col.4 + Col.5)
1	50.00	50.00	4500.00	3000	7500.00
2	85.00	42.50	3825.00	1500	5325.00
3	117.50	39.17	3525.30	1000	4525.30
4	152.25	38.06	3425.40	750	4175.40
5	191.38	38.28	3445.20	600	4045.20
6	236.16	39.36	3542.40	500	4042.40

Computation of Col. 2:

Month 1: $100 \times 0.5 = 50$



Month 2: $100 \times (0.5 + 0.1) + 50 \times 0.5 = 85$

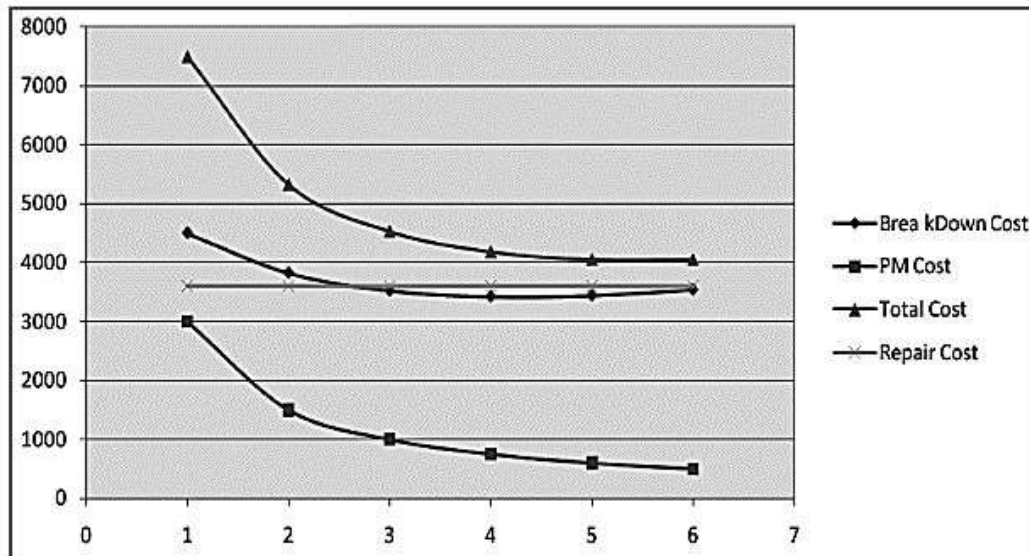
Month 3: $100 \times (0.5 + 0.1 + 0.1) + 50 \times 0.1 + 85 \times 0.5 = 117.5$

Month 4: $100 \times (0.5 + 0.1 + 0.1 + 0.1) + 50 \times 0.1 + 85 \times 0.1 + 117.5 \times 0.5 = 152.25$

Month 5: $100 \times (0.5 + 0.1 + 0.1 + 0.1 + 0.1) + 50 \times 0.1 + 85 \times 0.1 + 117.5 \times 0.1 + 152.25 \times 0.5 = 191.38$

Month 6: $100 \times (0.5 + 0.1 + 0.1 + 0.1 + 0.1 + 0.1) + 50 \times 0.1 + 85 \times 0.1 + 117.5 \times 0.1 + 152.25 \times 0.1 + 191.38 \times 0.5 = 236.16$

Graphical Representation Policy 1:



Repair Policy Cost of Policy 2 = Average number of repairs per month $\times$ Average repair cost on breakdown = $22.73 \times 90 = \text{Rs.} 2,045.7$ (Data taken from Solution 5).

Preventive Maintenance Costs for the Six Preventive Maintenance Cycles

Preventive Maintenance Cycle (n), months	Expected Breakdowns in PM Cycle	Average No of Breakdowns per month (Col.2/Col.1)	Expected Monthly Breakdown Cost (Col.3 $\times$ Rs.90)	Expected Monthly PM Cost (Rs.30 $\times$ 100)/ Col.1	Expected Monthly Cost of each PM cycle (Col.4 + Col.5)
1	10.00	10.00	900.00	3000	3900.00
2	21.00	10.50	945.00	1500	2445.00
3	33.10	11.03	992.70	1000	1992.70
4	46.41	11.60	1044.00	750	1794.00
5	71.05	14.21	1278.90	600	1878.90
6	119.16	19.86	1787.40	500	2287.40

Computation of Col. 2:

Month 1: $100 \times 0.1 = 10$

Month 2: $100 \times (0.1 + 0.1) + 10 \times 0.1 = 21$

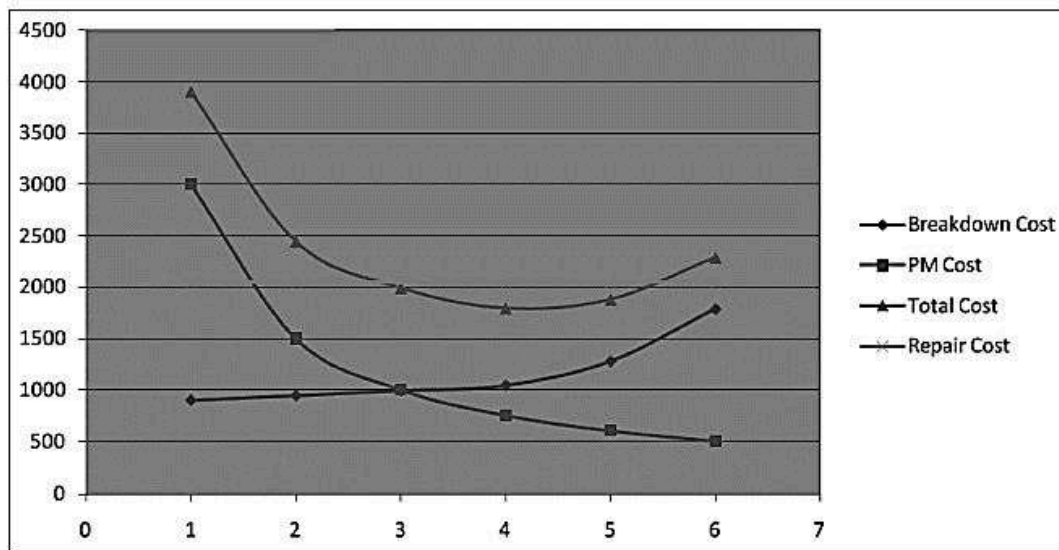
Month 3: $100 \times (0.1 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.1 = 33.1$

Month 4: $100 \times (0.1 + 0.1 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.1 + 33.1 \times 0.1 = 46.41$

Month 5: $100 \times (0.2 + 0.1 + 0.1 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.1 + 33.1 \times 0.1 + 46.41 \times 0.1 = 71.05$

Month 6: $100 \times (0.4 + 0.2 + 0.1 + 0.1 + 0.1 + 0.1) + 10 \times 0.2 + 21 \times 0.1 + 33.1 \times 0.1 + 46.41 \times 0.1 + 71.05 \times 0.1 = 119.16$

Graphical Representation Policy 2:



Repair Policy Cost of Policy 3 = Average number of repairs per month $\times$ Average repair cost on breakdown = $30.30 \times 90 = \text{Rs.}2,727$ (Data taken from Ans 1)

Preventive Maintenance Costs for the Six Preventive Maintenance Cycles

Preventive Maintenance Cycle (n), months	Expected Breakdowns in PM Cycle	Average No of Breakdowns per month (Col.2/Col.1)	Expected Monthly Breakdown Cost (Col.3 $\times$ Rs.90)	Expected Monthly PM Cost (Rs.30 $\times$ 100)/ Col.1	Expected Monthly Cost of each PM cycle (Col.4 + Col.5)
1	10.00	10.00	900.00	3000	3900.00
2	21.00	10.50	945.00	1500	2445.00
3	73.10	24.37	2193.30	1000	3193.30
4	94.41	23.60	2124.00	750	2874.00
5	118.25	23.65	2128.50	600	2728.50
6	160.92	26.82	2413.80	500	2913.80

Computation of Col. 2:

Month 1: $100 \times 0.1 = 10$

Month 2: $100 \times (0.1 + 0.1) + 10 \times 0.1 = 21$

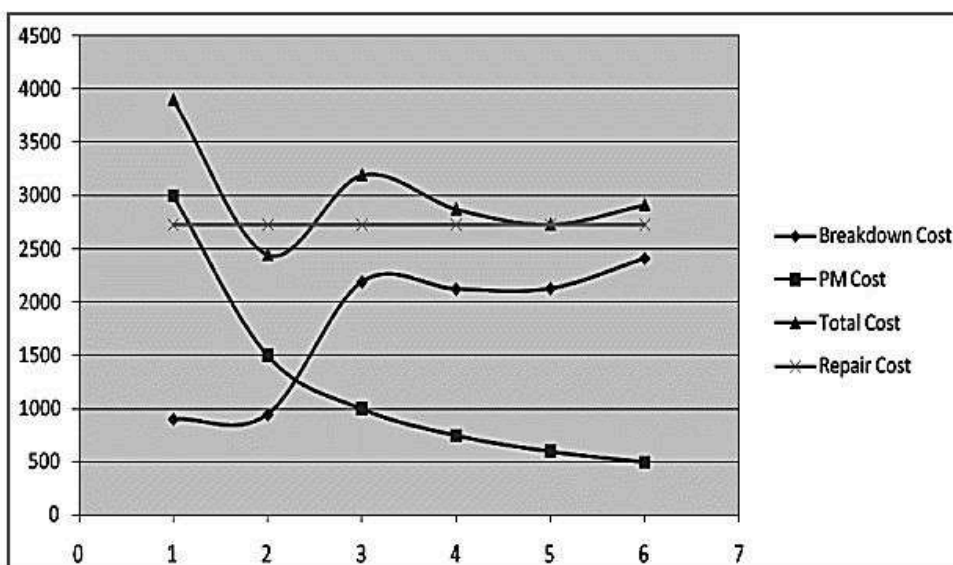
Month 3: $100 \times (0.5 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.1 = 73.1$

Month 4: $100 \times (0.1 + 0.5 + 0.1 + 0.1) + 10 \times 0.5 + 21 \times 0.1 + 73.1 \times 0.1 = 94.41$

Month 5: $100 \times (0.1 + 0.1 + 0.5 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.5 + 73.1 \times 0.1 + 94.41 \times 0.1 = 118.25$

Month 6: $100 \times (0.1 + 0.1 + 0.1 + 0.5 + 0.1 + 0.1) + 10 \times 0.1 + 21 \times 0.1 + 73.1 \times 0.5 + 94.41 \times 0.1 + 118.25 \times 0.1 = 160.92$

Graphical Representation Policy 3:



If we refer three graphs it is clear that -

Under Policy 1 (Fig -I) Repair cost Rs.3,600 is always less than cost of all PM cycles - Refer Col.6 of Table-I. Therefore if breakdown probability distribution is like under Policy 1, management will opt for policy of repairing machine when it breaks down.

Under Policy 2 (Fig -II) PM cycle of 4 months with the cost of Rs.1,794 - Refer Col.6, Row 4 of Table-II, is less than Repair cost Rs.2,045.7. Therefore, if breakdown probability distribution is like under Policy 2, management will opt for PM policy of 4 months instead of going for policy of repairing machine when it breaks down. This way management can save Rs.251.7.

On similar logic under policy 3 PM is preferable to Repair as and when required policy. But in comparison to policy 2, policy 3 is inferior as Repair cost under policy 2- Rs.2,045.7 < Repair cost under policy 3- Rs.2,727.

PM policy Cost under policy 2- Rs.1,794 < PM policy Cost under policy 3- Rs.2,445.

The decision concerning preventive maintenance versus Repair depends on i) factor costs C_R and C_{PM} ii) the breakdown probability distribution; besides other sensitivities.

Illustration 8:

Compute the requirement of spares for breakdown maintenance for an item that exhibits a Poissonian behavior for failure rates with a mean breakdown rate of five items per month. If the lead time for procuring these spares is one month and a service level of 90 per cent is to be used, what buffer stock of these items should be maintained? (A fixed re-order quantity system of inventory is being used).

Answer:

Buffer stock is required to cover the lead time only, i.e. to cover one month's period.

Mean consumption rate = 5 per month

Referring to the Poisson distribution table for $a = 5$, we have for

$x = 7$... Cumulative probability = 0.867

$x = 8$... Cumulative probability = 0.932

Thus, with seven items only 86.7 per cent service level is attained; with eight items 93.2 per cent service level is obtained. Since one would err on the higher side of the service level, the value of $x = 8$ is chosen.



This means, the amount of spares stock that has to be kept must correspond to a maximum demand rate D_{max} of eight during the lead time. In other words we should keep a Buffer Stock = $D_{max} - D_{average}$ during a lead time = $8 - 5 = 3$ items.

Thus, buffer stock desired is three numbers of the given spare part.

Illustration 9:

The main shaft of an equipment has a very high reliability of 0.990. The equipment comes from Russia and has a high downtime cost associated with the failure of this shaft. This is estimated at Rs. 2 crore as the costs of sales lost and other relevant costs. However, this spare is quoted at Rs. 10 lakh at present. Should the shaft spare be procured along with the equipment and kept or not?

Answer:

The expected cost of down-time

= (Probability of failure) × (Cost when break-down occurs)

= $(1 - 0.990) \times (\text{Rs. 2 crore}) = \text{Rs. 2 lakh}$

However, the cost of procuring the spare now is Rs. 10 lakh. Therefore, expected cost of downtime is less than the cost of spare; hence the spare need not be bought along with the equipment.

Illustration 10:

PQR company has kept records of breakdowns of its machines for 300 days work year as shown below:

No. of breakdown	Frequency in days
0	40
1	150
2	70
3	30
4	10
	300

The firm estimates that each breakdown costs Rs. 650 and is considering adopting a preventive maintenance program which would cost Rs. 200 per day and limit the number of breakdown to an average of one per day. What is the expected annual savings from preventive maintenance program?

Answer:

Step 1 : To determine the expected number of breakdowns per year:

No. of breakdowns (x)	Frequency of breakdowns in days i.e, f(x)	Probability distribution of breakdowns P(x)	Expected value of breakdowns X P(x)
0	40	$40/300 = 0.133$	Nil
1	150	$150/300 = 0.500$	0.500
2	70	$70/300 = 0.233$	0.466
3	30	$30/300 = 0.100$	0.300
4	10	$10/300 = 0.033$	0.132
Total	300	1.000	1.400

Step 2 :

Total no. of breakdowns per day = 1.40

Cost of breakdown per day = $1.40 \times 650 = \text{Rs. 910}$

Cost of preventive maintenance programme per day = Rs. 200 + Rs. 650 = Rs. 850

Expected annual savings from the preventive maintenance programme = $(910 - 850) \times 300$ days

$$= 60 \times 300 = \text{Rs. } 18,000$$

Illustration 11:

A firm is using a machine whose purchase price is Rs. 15,000. The installation charges amount to Rs. 3,500 and the machine has a scrap value of only Rs. 1,500 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table:

Year	1	2	3	4	5	6	7	8	9
Maintenance Cost (Rs.)	260	760	1100	1600	2200	3000	4100	4900	6100

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year end.

Answer:

Cost of machine, $C = \text{Rs. } 15,000 + \text{Rs. } 3,500 = \text{Rs. } 18,500$

Scrap value, $S = \text{Rs. } 1,500$.

Year	Maintenance Cost, M_1 (Rs.)	Cumulative Maintenance Cost, ΣM_1 (Rs.)	Cost of Machine - Scrap Value (Rs.)	Total Cost $T_{(n)}$ (Rs.)	Annual Cost $A_{(n)}$ (Rs.)
(i)	(ii)	(iii)	(iv)	(v) = (iii)+(iv)	(vi) = (v)/n
1	260	260	17,000	17,260	17,260
2	760	1,020	17,000	18,020	9,010
3	1,100	2,120	17,000	19,120	6,373
4	1,600	3,720	17,000	20,720	5,180
5	2,200	5,920	17,000	22,920	4,584
6	3,000	8,920	17,000	25,920	4,320
7	4,100	13,020	17,000	30,020	4,288*
8	4,900	17,920	17,000	34,920	4,365
9	6,100	24,020	17,000	41,020	4,557

Lowest average cost is Rs.4,288 approx., which corresponds to $n = 7$ in above table. Thus machine needs to be replaced every 7th year.

Illustration 12:

A large computer installation contains 2,000 components of identical nature which are subject to failure as per probability distribution that follows:

Month End:	1	2	3	4	5
% Failure to date:	10	25	50	80	100

Components which fail have to be replaced for efficient functioning of the system. If they are replaced as and when failures occur, the cost of replacement per unit is Rs.3. Alternatively, if all components are replaced in one lot at periodical intervals and individually replace only such failures as occur between group replacement, the cost of component replaced is Rs. 1.

(a) Assess which policy of replacement would be economical.

(b) If group replacement is economical at current costs, then assess at what cost of individual replacement would group replacement be uneconomical.

(c) How high can the cost per unit in-group replacement be to make a preference for individual replacement policy?

Answer:

(a) Computation of failures & Mean life

Month (X)	Probability of Failure (P)	P X	Average Life of a component = 3.35 Months
1	0.10	0.10	
2	0.15	0.30	
3	0.25	0.75	
4	0.30	1.20	
5	0.20	1.00	
		$\Sigma p_{ixi} = 3.35$ month	

Average No. of Replacements = $2000/3.35 = 597$ per month

Cost of Individual Replacement = $597 \times \text{Rs. } 3 = \text{Rs. } 1791$ per month

Computation of expected No. of Replacements:

Month	Expected number of components to be replaced by the month end	
1	$N_1 = NOP_1 = 2000 \times 0.1$	200
2	$N_2 = NOP_2 + N_1P_1 = 2000 \times 0.15 + 200 \times 0.1$	320
3	$N_3 = NOP_3 + N_1P_2 + N_2P_1 = 2000 \times 0.25 + 200 \times 0.15 + 320 \times 0.1$	562
4	$N_4 = NOP_4 + N_1P_3 + N_2P_2 + N_3P_1 = 2000 \times 0.3 + 200 \times 0.25 + 320 \times 0.15 + 562 \times 0.1$	754.2
5	$N_5 = NOP_5 + N_1P_4 + N_2P_3 + N_3P_2 + N_4P_1 = 2000 \times 0.2 + 200 \times 0.3 + 320 \times 0.25 + 562 \times 0.15 + 754.2 \times 0.1$	699.72

Computation of Average cost

Month (x)	Cumulative number of component Replace individually by month end	Cost		Total Cost (Tc)	Average Cost = T_c/n
		Individual	Group		
		Rs	. Rs.	Rs.	Rs. per month
1	200	600	2000	2600	2600
2	520	1560	2000	3560	1780
3	1082	3246	2000	5246	1748.67*
4	1836.2	5508.6	2000	7508.6	1877.15
5	2535.92	7607.76	2000	9607.76	1921.55

Since the average cost is lowest in 3rd month, the optimal interval i.e. replacement is 3 months. Also the average cost is less than Rs. 1791 of individual replacement, the group replacement policy is better.

(b) Let 'K' be the cost of Individual Replacement

Month	Average Cost of Group Replacement	Average cost of Individual Replacement	'K' Value* (Rs.)	* To obtain the value of K use the equation Average cost of Individual Replacement = Average Cost of Group Replacement
1	$(2000 + 200 K)/1$	597 K	5.04	
2	$(2000 + 520 K)/2$	597 K	2.97	
3	$(2000 + 1082 K)/3$	597 K	2.82	
4	$(2000 + 1836.2 K)/4$	597 K	3.62	
5	$(2000 + 2535.92 K)/5$	597 K	4.45	

If group replacement is anything smaller than 2.82, then Group Replacement would be uneconomical.

(c) Let 'a' be the unit cost of Group Replacement Policy

Month	Average Cost of Group Replacement	Average of Individual Replacement	'a' Value (Rs.)
1	$(2000a + 600)/1$	1791	0.60
2	$(2000a + 1560)/2$	1791	1.01
3	$(2000a + 3246)/3$	1791	1.06
4	$(2000a + 5508.6)/4$	1791	0.83
5	$(2000a + 7607.76)/5$	1791	0.67

When unit cost is more than Rs. 1.06 then Individual Replacement policy would be better.

Illustration 13:

An electric company which generates and distributes electricity conducted a study on the life of poles. The repatriate life data are given in the following table:

Life data of electric poles

Year after installation:	1	2	3	4	5	6	7	8	9	10
Percentage poles failing:	1	2	3	5	7	12	20	30	16	4

- If the company now installs 5,000 poles and follows a policy of replacing poles only when they fail, how many poles are expected to be replaced each year during the next ten years?
To simplify the computation assume that failures occur and replacements are made only at the end of a year.
- If the cost of replacing individually is Rs. 160 per pole and if we have a common group replacement policy it costs Rs. 80 per pole, find out the optimal period for group replacement.

Answer:

Chart showing Optimal Replacement Period

Average life of the pole - $1 \times 0.01 + 2 \times 0.02 + 3 \times 0.03 + 4 \times 0.05 + 5 \times 0.07 + 6 \times 0.12 + 7 \times 0.20 + 8 \times 0.3 + 9 \times 0.16 + 10 \times 0.04 = 7.05$ years.

No. of poles to be replaced every year = $5000 / 7.05 = 709$

Average yearly cost on individual replacement = $709 \times \text{Rs.}160 = \text{Rs.}1,13,440$.

Group Replacement: Initial Cost = $5,000 \times \text{Rs.}80 = \text{Rs.}4,00,000$.

Year	No. of poles to be replaced	Yearly cost of individual replacement @ Rs. 160/pole (Rs.)	Cumulative cost of individual replacement (Rs.)	Total cost of individual replacement as well as group replacement (Rs.)	Average Annual Cost = Total Cost / Year (Rs.)
1	$5,000 \times 0.01 = 50$	8,000	8,000	4,08,000	4,08,000
2	$5,000 \times 0.02 + 50 \times 0.01 = 101$	16,160	24,160	4,24,160	2,12,080
3	$5,000 \times 0.03 + 50 \times 0.02 + 101 \times 0.01 = 152$	24,320	48,480	4,48,480	1,49,493
4	$5,000 \times 0.05 + 50 \times 0.03 + 101 \times 0.02 + 152 \times 0.01 = 256$	40,960	89,440	4,89,440	1,22,360
5	$5,000 \times 0.07 + 50 \times 0.05 + 101 \times 0.03 + 152 \times 0.02 + 256 \times 0.01 =$	57,920	1,47,360	5,47,360	1,09,472

	362				
6	$5,000 \times 1.2 + 50 \times 0.07 + 101 \times 0.05 + 152 \times 0.03 + 256 \times 0.02 + 362 \times 0.01 = 6023$	9,63,680	11,11,040	15,11,040	2,51,840

Optimal replacement at the end of the 5th year.

Illustration 14:

Product A has a Mean Time Between Failures (MTBF) of 30 hours and has a Mean Time To Repairs (MTTR) of 5 hours. Product B has a MTBF of 40 hours and has a MTTR of 2 hours.

- Which product has the higher reliability?
- Which product has greater maintainability?
- Which product has greater availability?

Answer:

- Product B, with higher MTBF (i.e. 40 hours) than Product A (i.e. 30 hours), is more reliable since it has lesser chance of failure during servicing.
- By MTTR we mean the time taken to repair a machine and put it into operation. Thus Product B, with lesser MTTR (i.e., 2 hours) than Product A (i.e., 5 hours), has greater maintainability.
- Availability of a machine/product = $\frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$
 Therefore, Availability of Product A = $30 / (30 + 5) = 30 / 35 = 85.714\%$ Availability of Product B = $40 / (40 + 2) = 40 / 42 = 95.238\%$
 Hence, Product B has more availability.

Illustration 15:

Maharashtra Trucking Company (MTC) has a fleet of 50 trucks. The past data on the breakdown of the trucks show the following probability distribution (for a new truck as well as for one which has been repaired after a breakdown).

Months after Maintenance	Probability of Breakdown
1	0.10
2	0.20
3	0.30
4	0.40

Each breakdown costs Rs. 3,000 on an average; which includes cost of time lost and cost of materials and manpower.

The manager of MTC knows the importance of preventive maintenance. He estimates the costs of the preventive maintenance to be Rs. 500 per such preventive action. What should be the appropriate maintenance policy in terms of the mix of preventive and breakdown maintenance

Answer:

First, let us compute the cost of a totally breakdown maintenance policy.

The expected number of months between failures

$$= 0.1 (1) + 0.2 (2) + 0.3 (3) + 0.4 (4) = 3.0$$

Cost per month of totally breakdown maintenance policy=

$$\frac{(\text{No. of trucks}) (\text{Cost per breakdown})}{(\text{Expected number of months between failure})}$$

$$= \frac{(50)(\text{Rs. } 3000)}{(3.0)} = \text{Rs. } 50,000$$

Now let us compute the costs of different periodicities of preventive maintenance.

(i) Preventive maintenance (PM) period one month

No. of breakdowns within the period of one month:

$$B1 = (50) \times (0.1) = 5$$

$$\text{Cost of breakdown} = 5 \times \text{Rs. } 3000 = \text{Rs. } 15,000$$

$$\text{Cost of preventive maintenance} = \text{Rs. } 500 \times 50 = \text{Rs. } 25,000$$

$$\text{Total Cost during the PM period} = \text{Rs. } 40,000$$

Therefore, cost per month for this policy is

$$= 40,000 \div 1 = \text{Rs. } 40,000$$

(ii) Preventive maintenance (PM) period two months

No. of breakdowns within 2 months:

$$B2 = (50) \times (0.1 + 0.2) + (50) \times (0.1) \times (0.1) = 15.5$$

$$\text{Cost of breakdown} = (15.5) \times \text{Rs. } 3000 = \text{Rs. } 46,500$$

$$\text{Cost of prev. maintenance} = \text{Rs. } 500 \times 50 = \text{Rs. } 25,000$$

$$\text{Total cost during the PM period} = \text{Rs. } 71,500$$

Therefore, cost per month for this policy:

$$\text{Rs. } 71,500 \div 2 \text{ months} = \text{Rs. } 35,750$$

(iii) Preventive maintenance period 3 months

No. of breakdowns within 3 months:

$$B3 = (50) \times (0.1 + 0.2 + 0.3) + (50 \times 0.1) (0.1 + 0.2) + (50 \times 0.1 \times 0.1) (0.1) \\ = 30 + 1.5 + 0.05 = 31.55$$

$$\text{Cost of breakdown} = 31.55 \times \text{Rs. } 3000 = \text{Rs. } 94,650$$

$$\text{Cost of preventive maintenance} = 50 \times \text{Rs. } 500 = \text{Rs. } 25,000$$

$$\text{Total} = \text{Rs. } 1,19,650$$

Therefore, cost per month for this policy

$$= \text{Rs. } 1,19,650 \div 3 \text{ months} = \text{Rs. } 39,883.33$$

(iv) Preventive maintenance period 4 months

No. of breakdowns within 4 months

$$B4 = [(50) \times (1.0)] + [(50) \times (0.1) \times (0.1 + 0.2 + 0.3) + (50 \times 0.1 \times 0.1) \times (0.1 + 0.2) + (50 \times 0.1 \times 0.1 \times 0.1) \\ \times (0.1) + (50 \times 0.1 \times 0.2) \times (0.1)] + [(50 \times 0.2) \times (0.1 + 0.2) + (50 \times 0.2 \times 0.1) \times (0.1)] + [(50 \times 0.3 \times (0.1))] \\ = 57.855$$

$$\text{Cost of breakdown} = (57.855) \times (\text{Rs. } 3,000) = \text{Rs. } 1,73,565$$

$$\text{Cost of preventive maintenance} = 50 \times \text{Rs. } 500 = \text{Rs. } 25,000$$

$$\text{Total} = \text{Rs. } 1,98,565$$

Therefore, cost per month for this policy is $\text{Rs. } 1,98,565 \div 4 \text{ months} = \text{Rs. } 49,641.25$

Comparing the costs per month of different policies, we see that the policy of preventive maintenance every two months is the most economic policy.

THEORY QUESTIONS

Question 1.

1. What are the different types of maintenance? Explain each with examples.
2. Distinguish between Breakdown Maintenance and Routine Maintenance. Give examples.
3. Why is Preventive Maintenance important? How does it help avoid equipment failure?
4. What is Predictive Maintenance? How does technology help in this type of maintenance?
5. Give examples of maintenance tasks in a factory or office. Classify them into different types.

Maintenance is essential for ensuring the longevity and efficiency of machinery, equipment, and systems. There are four primary types of maintenance, each with distinct strategies and benefits:

1. Break Down Maintenance

Definition: Also known as reactive maintenance, this strategy involves repairing equipment after it has failed. This type of maintenance is unplanned and performed only when necessary.

Example: In a manufacturing plant, if a conveyor belt suddenly breaks down, the maintenance team fixes it on an emergency basis to resume production.

Pros:

- Less initial investment in planning and monitoring.
- Can be more cost-effective for non-critical equipment.

Cons:

- Can result in unexpected downtime and higher repair costs.
- Can lead to severe damage if not addressed promptly.

2. Preventive Maintenance

Definition: This maintenance strategy involves regular, scheduled maintenance tasks to prevent equipment failure. It is based on time or usage metrics.

Example: In the aviation industry, airplanes undergo regular inspections and maintenance based on flight hours to ensure safety and prevent unexpected failures.

Pros:

- Reduces the likelihood of unexpected failures.
- Extends the lifespan of equipment.
- Enhances safety and reliability.

Cons:

- Can be more costly due to regular inspections and part replacements.
- Might involve unnecessary maintenance if the equipment is still in good condition.

3. Routine Maintenance

Definition: Routine maintenance includes simple, regular tasks that keep equipment in working order. These tasks are often minor and performed frequently.

Example: In an office building, tasks like changing air filters, lubricating moving parts, and inspecting lighting systems are part of routine maintenance.

Pros:

- Keeps equipment running smoothly and efficiently.
- Minimizes minor issues that could escalate into major problems.
- Often involves low-cost tasks.

Cons:

- Requires consistent attention and resource allocation.
- May not prevent all types of significant failures.

4. 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.

Pros:

- Minimizes unplanned downtime.
- Reduces maintenance costs by addressing issues only when necessary.
- Enhances the reliability and efficiency of equipment.

Cons:

- High initial cost for implementing monitoring technologies.
- Requires skilled personnel to analyze data and make accurate predictions.

Concept Essay: Advantages of Preventive Maintenance

Question 2.

1. Discuss the key advantages of implementing a preventive maintenance system in industrial operations.
2. Explain how preventive maintenance contributes to productivity, safety, and cost-efficiency in manufacturing.
3. Evaluate the impact of preventive maintenance on equipment longevity and industrial relations.

Introduction

In modern industrial environments, equipment reliability and operational continuity are paramount. Preventive maintenance (PM) is a proactive strategy that emphasizes regular inspection, servicing, and minor repairs to avoid unexpected breakdowns. Rooted in the principle that "prevention is better than cure," PM not only safeguards machinery but also enhances productivity, safety, and organizational harmony.

Key Advantages of Preventive Maintenance

1. Reduced Breakdowns and Downtime

Preventive maintenance ensures that potential faults are identified and addressed before they escalate. Regular inspections and servicing minimize unplanned stoppages, allowing production to flow uninterrupted.

Example: Routine lubrication of conveyor belts prevents sudden halts in packaging lines, ensuring consistent throughput.

2. Greater Safety to Workers

Well-maintained equipment significantly lowers the risk of workplace accidents. By eliminating hazards such as electrical faults or mechanical failures, PM fosters a safer environment for all personnel.

Example: Periodic checks of electrical panels help prevent short circuits and potential fire hazards.

3. Fewer Large-Scale Repairs

Addressing minor issues early prevents them from developing into major failures. This approach reduces the need for extensive overhauls and lowers maintenance costs.

Example: Replacing worn-out bearings in time avoids damage to entire motor assemblies.

4. Less Standby or Reserve Equipment/Spares

Reliable machinery reduces dependency on backup systems and excess inventory. This leads to better resource utilization and capital efficiency. **Example:** A well-maintained boiler eliminates the need for a secondary unit on standby, saving both space and investment.

5. Lower Unit Cost of Product Manufactured

By minimizing breakdowns and maximizing uptime, PM enhances production efficiency. This results in lower operational costs per unit and improved profitability.

Example: Consistent machine uptime leads to higher output with reduced overhead, lowering the unit cost of production.

6. Better Product Quality

Stable equipment performance ensures uniformity in output and reduces defects. Preventive care maintains precision and consistency in manufacturing processes.

Example: Regular maintenance of cutting tools ensures accurate dimensions and minimizes rework.

7. Increased Equipment Life

Timely servicing and calibration extend the functional lifespan of machinery. This delays the need for replacements and reduces capital expenditure.

Example: Scheduled cleaning and calibration of CNC machines prolong their usability and maintain performance standards.

8. Better Industrial Relations

Smooth operations foster a positive work culture. When equipment functions reliably and worker safety is prioritized, morale improves and trust between management and staff strengthens.

Example: Workers feel valued when their safety and tools are maintained, leading to better cooperation and reduced conflict.

Conclusion

Preventive maintenance is not merely a technical protocol—it is a strategic investment in operational excellence. Its multifaceted benefits span productivity, safety, cost-efficiency, and workforce engagement. Organizations that adopt PM systems position themselves for long-term sustainability and competitive advantage.

Concept Essay: Distinguishing Between Routine and Predictive Maintenance

Question 3. Distinguish between Routine and Predictive maintenance?

Introduction

In industrial operations, maintenance strategies play a pivotal role in ensuring equipment reliability, minimizing downtime, and optimizing productivity. Among the various approaches, **Routine Maintenance** and **Predictive Maintenance** stand out as two distinct yet complementary systems. While both aim to prevent equipment failure, they differ significantly in methodology, timing, and technological reliance.

Routine Maintenance:

Definition: Routine Maintenance refers to **regular, scheduled activities** such as lubrication, cleaning, and minor repairs, often performed while equipment is running or during planned shutdowns.

Key Features:

- Based on fixed time intervals or usage cycles.
- Does not rely on real-time data.
- Ensures consistent upkeep and operational readiness.

Example: Lubricating conveyor belts during scheduled breaks prevents wear and tear, ensuring smooth packaging operations without interrupting production.

Advantages:

- Simple to implement.
- Reduces gradual wear and tear.
- Minimizes sudden disruptions through habitual care.

Predictive Maintenance:**Definition:**

Predictive Maintenance uses **real-time monitoring and data analytics** to forecast equipment failure. Maintenance is performed **just before** the predicted breakdown, maximizing uptime and resource efficiency.

Key Features:

- Relies on sensors and software to track equipment health.
- Maintenance is condition-based, not time-based.
- Enables proactive intervention with minimal waste.

Example:

In a power plant, sensors monitor turbine vibrations. When abnormal patterns emerge, maintenance is scheduled before the turbine fails—avoiding costly downtime and damage.

Advantages:

- Reduces unnecessary maintenance.
- Extends equipment life through precision care.
- Minimizes downtime and enhances cost-effectiveness.

Comparative Analysis

Aspect	Routine Maintenance	Predictive Maintenance
Basis	Time or usage intervals	Real-time condition monitoring
Technology Dependency	Low	High (sensors, analytics software)
Timing	Scheduled, regardless of condition	Just before predicted failure
Cost Efficiency	Moderate	High (due to targeted intervention)
Risk of Over-Maintenance	Possible	Minimal
Implementation Complexity	Simple	Requires infrastructure and expertise

Conclusion

Routine Maintenance and Predictive Maintenance represent two ends of the maintenance spectrum—one rooted in schedule, the other in intelligence. While routine methods offer simplicity and consistency, predictive strategies deliver precision and efficiency. A balanced integration of both can empower industries to achieve optimal equipment performance, reduce costs, and enhance operational resilience.

Types of Spare Parts:**Question 4.**

1. "Explain the classification of spare parts used in industrial maintenance. How does each category contribute to equipment reliability and cost optimization?"
2. "Distinguish between Regular Spares and Rotable Spares with suitable examples. Discuss how their management impacts maintenance planning."
3. "Discuss the role of Insurance Spares in critical operations. Why are they considered a strategic investment despite infrequent usage?"
4. "Evaluate the significance of Capital Spares in long-term asset management. How do procurement timing and cost considerations influence their usage?"
5. "Using a centrifugal pump as a reference, classify its spare parts into Regular, Rotable, Insurance, and Capital categories. Justify the classification with operational rationale."

In industrial operations, the reliability of equipment is paramount. Downtime not only disrupts productivity but can also lead to significant financial losses. To mitigate such risks, organizations rely on a strategic inventory of spare parts. These components are categorized based on their usage frequency,

criticality, and cost implications. Understanding these categories is essential for effective maintenance planning, budgeting, and operational resilience.

Overview

Spare parts serve as the backbone of maintenance systems. Their classification helps maintenance managers prioritize procurement, optimize inventory levels, and ensure timely availability during breakdowns or scheduled servicing. Broadly, spare parts fall into four categories: **Regular Spares**, **Rotable Spares**, **Insurance Spares**, and **Capital Spares**.

1. Regular Spares

Definition:

Regular spares are components consumed frequently during routine maintenance activities. They are typically low-cost items with moderate reliability and are stocked in substantial quantities.

Key Characteristics:

- Low unit cost
- High consumption rate
- Essential for scheduled servicing

Example (Centrifugal Pump):

- Gaskets, seals, nuts & bolts
- These parts are replaced periodically to maintain equipment efficiency and prevent minor failures from escalating.

Operational Insight:

Regular spares form the bulk of maintenance inventories. Their availability ensures uninterrupted servicing and reduces the risk of minor faults leading to major breakdowns.

2. Rotable Spares

Definition:

Rotable spares are high-value components that are periodically removed from service for repair or refurbishment and then rotated back into operation.

Key Characteristics:

- High initial cost
- Reusable after overhaul
- Cost-effective over long-term use

Example (Centrifugal Pump):

- Impeller, motor bearings, shaft sleeves
- These parts undergo scheduled refurbishment and are reinstalled, reducing the need for frequent replacements.

Operational Insight:

Rotable spares support predictive maintenance strategies. Their cyclical use reduces capital expenditure while maintaining equipment performance.

3. Insurance Spares

Definition:

Insurance spares are critical components kept in reserve to replace failed parts in essential equipment where downtime incurs substantial losses.

Key Characteristics:

- Rarely used but vital
- High impact on operational continuity
- Stored as a safeguard against unexpected failures

Example (Centrifugal Pump):

- Pump casing, motor assembly
- Having these spares on hand prevents prolonged outages and protects against revenue loss during emergencies.

Operational Insight:

Though seldom used, insurance spares are indispensable in high-stakes environments such as power plants, refineries, and manufacturing units with continuous operations.

4. Capital Spares**Definition:**

Capital spares are high-value items that are part of the original equipment investment. They are typically procured during the initial purchase and are not stocked routinely.

Key Characteristics:

- Long lead time
- High procurement cost
- Integral to equipment longevity

Example (Centrifugal Pump):

- Pump housing, drive shaft, base frame
- These components are essential for major overhauls and long-term asset sustainability.

Operational Insight:

Capital spares are strategic investments. Their availability ensures that critical equipment can be restored to original specifications without waiting for lengthy procurement cycles.

Conclusion

The classification of spare parts into Regular, Rotable, Insurance, and Capital categories provides a framework for efficient maintenance planning. Each type plays a distinct role in ensuring equipment reliability, minimizing downtime, and optimizing lifecycle costs. For operations managers and maintenance planners, understanding these categories is not just academic—it's a strategic imperative that directly influences productivity, profitability, and asset integrity.

QUESTIONS FROM PYP'S

Question 1.

(Dec 24 7M)

A computer of ROPAM Ltd., has 1000 nos. of Electronic Tubes.

They are subject to Mortality as given below:

Period	Age at Failures (Hrs.)	Probability of Failure
1	0 - 200	0.10
2	201 - 400	0.26
3	401 - 600	0.35
4	601 - 800	0.22
5	801 - 1000	0.07

If the tubes are group replaced, the cost of replacement is 150 per Electronic tube. Group replacement can be done at fixed intervals in the night shift when the computer is not normally used. Replacement of individual Electronic tubes which fail in Service Cost 600 per Electronic tube.

Assume that:

- (1) Electronic Tubes that fail during a period are replaced just before the end of the period.
- (2) The actual percentage of failure during a period for a sub-population of the Tubes with the same age is the same as the expected percentage of failure during the period for that sub-population.

Required:

- (i) Analyze the number of Electronic Tubes to be replaced every period.
- (ii) Assess the failure costs (R) on average of individual replacement of electronic tubes.
- (iii) Identify at what interval of time the Company should replace all the electronic Tubes.
- (iv) Advice which policy of replacement will be economical to the Company

Answer:

(i)

Individual Replacement (IR):

Period (x)	Probability of Failure (p)	(px)
1	0.10	0.10
2	0.26	0.52
3	0.35	1.05
4	0.22	0.88
5	0.07	0.35
TOTAL		2.9

Individual replacement cost for 2.9 period = $600 \times 1000 = \text{Rs. } 6,00,000$

(ii) Individual replacement Cost per period = $\text{Rs. } 6,00,000 / 2.9 = \text{Rs. } 206896.55$

Group Replacement:

Period (a)	Group Replacement Cost (GRC) (Rs.) (b)	GRC/month (Rs.) (c)	Cum. No. of IR (d)	IR/month (e)	IR cost/month (f)	Total Cost/Month (c + f)
1	$150 \times 1,000 = 1,50,000$	1,50,000	100	100	60,000	2,10,000
2	1,50,000	75,000	370	185	1,11,000	1,86,000
3	1,50,000	50,000	773	257.667	1,54,600	2,04,600

4	1,50,000	37,500	1138.5	284.625	1,70,775	2,08,275
5	1,50,000	30,000	1466.33	293.266	1,75,960	2,05,960

Calculation of No. of Individual Replacement (IR):

1000 Tubes	1	2	3	4	5
Failure (%)	0.10	0.26	0.35	0.22	0.07
	100	260	350	220	70
Failure (%)		0.10	0.26	0.35	0.22
		10	26	35	22
		270	0.10	0.26	0.35
Failure (%)			27	70.2	94.5
			403	0.10	0.26
				40.3	104.78
Failure (%)				365.5	
					327.83
Failure (%)					0.10
					36.55
					327.83

(iii) In 2 period's interval the Company should replace all the electronic Tubes as it leads to minimum cost of Rs. 1,86,000

(iv) It is economical to go for Group Replacement as it is cheaper than individual replacement

Question 2.

(Jun 24 7M)

RON TIX Ltd., a fleet owner finds from its past records that the cost per year of running a truck whose purchase price is ₹ 6,00,000 are as given below:

Years:	1	2	3	4	5	6	7	8
Running Costs (₹ in Thousand)	100	120	140	180	230	280	340	400
Re-Sales Price (₹ in Thousand)	300	150	75	37.50	20	20	20	20

(Assume that Cost of Money is zero)

Required:

(i) Assess the average annual cost of trucks for each year.

(ii) Analyze and Infer at what age the truck should be replaced on economic consideration.

Answer:

Let C = Capital cost = Rs. 6,00,000/- , $S(y)$ = Scrap value changes yearly, $G(y)$ Average yearly cost, $u(t)$ = Annual maintenance cost

Years (t) = y	Running Cost u (y) in Rs.	Cumulative Running cost M (y) in Rs.	Resale value S (y) in Rs.	$C - S$ (y) In Rs.	$T(y) = C$ - $S(y) +$ $M(y)$	Average cost in Rs.	$G(y) =$ $T(y) /$ y
1	100	100	300	300	400	400	400
2	120	220	150	450	670	335	335
3	140	360	75	525	885	295	295
4	180	540	37.50	562.50	1102.5	275.6	275.6
5	230	770	20	580	1350	270	270
6	280	1050	20	580	1630	271.7	271.7

7	340	1390	20	580	1970	281.4	281.4
8	400	1790	20	580	2370	296.2	296.2

From the table above we can see that the $G(y)$ is minimum at the end of 5th year. Hence the truck is to be replaced at the end of 5th year.

Question 3.**(Dec 23 7M)**

The Management of BB HOTEL IN is considering periodic replacement of light bulbs fitted in its rooms. There are 200 rooms in the hotel and each room has 5 bulbs. The Management is conducting a study on the life of the light bulbs. The following mortality rates have been observed for the light bulbs.

Month of USE	1	2	3	4	5
Percent of bulbs failing by that month	10	15	25	30	20

There are 1000 light bulbs in use and it costs Rs. 100 to replace an individual bulb which has burnt out. If all bulbs were replaced simultaneously, it would cost Rs. 20 per bulb. It is proposed to replace all bulbs at fixed intervals, whether or not they have burnt out and to continue replacing burnt out bulbs as they fail.

Required:

- Examine the number of light bulbs to be replaced every month.
- Calculate the average monthly cost (Rs.) of individual replacement.
- Identify at what interval of time the Management of BB Hotel IN should replace all the light bulbs and which light bulbs and which policy of replacement would be economical.

Answer:

If P_i is the probability of failure of new bulb in i^{th} month, then

$$P_1 = 10/100 = 0.10$$

$$P_2 = 15/100 = 0.15$$

$$P_3 = 25/100 = 0.25$$

$$P_4 = 30/100 = 0.30$$

$$P_5 = 20/100 = 0.20$$

$$\text{Here, } P_1 + P_2 + P_3 + P_4 + P_5 = 1$$

Since the sum of all probabilities is equal to 1

$\therefore P_6, P_7, \dots$ are all zeroes.

Therefore, a bulb cannot survive for more than 5 months, i.e., bulb has survived for four months and is sure to fail in the fifth month.

Assuming that the burnt out bulbs in any month are replaced just at the end of that month. If N_i be the number of replacement at the end of i^{th} month, while all 1000 bulbs were new initially, then we have

$N_0 = \text{No. of bulbs in the beginning} = 1000$

Computation of No. of lights bulbs to be replaced every month:

Month	Except no. of bulbs to be replaced by the month end	
1	$N_1 = \text{No. of burnt out bulbs replaced at the end of 1st month}$ $= N_0 P_1 = 1000 * 0.10$	100
2	$N_2 = \text{No. of burnt out bulbs replaced at the end of 2nd month}$ $= N_0 P_2 + N_1 P_1 = 1000 * 0.15 + 100 * 0.10$	160
3	$N_3 = \text{No. of burnt out bulbs replaced at the end of 3rd month}$	281



	$= NOP3 + N1P2 + N2P1 = 1000 * 0.25 + 100 * 0.15 + 160 * 0.10$	281
4	$N4 = \text{No. of burnt out bulbs replaced at the end of 4th month}$ $= NOP4 + N1P3 + N2P2 + N3P1 = 1000 * 0.30 + 100 * 0.25 + 160 * 0.15 + 281 * 0.10$	377
5	$N5 = \text{No. of burnt out bulbs replaced at the end of 5th month}$ $= NOP5 + N1P4 + N2P3 + N3P2 + N4P1$ $= 1000 * 0.20 + 100 * 0.30 + 160 * 0.25 + 281 * 0.15 + 377 * 0.10$	350

Computation of cost of individual replacement.

Month (X)	Probability of failure (P)	PX
1	0.10	0.10
2	0.15	0.30
3	0.25	0.75
4	0.30	1.20
5	0.20	1.00
		$\Sigma P_i X_i = 3.35 \text{ Month}$

Average life of bulbs = 3.35 Months

Avg. no. of Replacements = $1000/3.35 = 298$ (approx) per month

Cost of individual replacement = $298 * 7100 = 729,800/\text{month}$

Computation of Average Cost:

Month (X)	Cumulative no. of components replaced individually by month end	Cost Individual (₹)	Cost Group (₹)	Total Cost (TC) (₹)	Avg. Cost = TC/n (₹/month)
1	100	10,000	20,000	30,000	30,000
2	260	26,000	20,000	46,000	23,000
3	541	54,100	20,000	74,100	24,700
4	918	91,800	20,000	1,11,800	27,950
5	1268	1,26,800	20,000	1,46,800	29,360

Since the average cost is lowest in the 2nd month, the optimal interval for replacement is 2 months.

Also the average cost is less than 29,800 of individual replacement, the group replacement is better

Question 4.

(Dec 23 7M)

VITNA Ltd., a Manufacturing Company, from its past experience estimates that maintenance cost per year in a machine which purchase price is ₹ 150000 and the resale value of machine will be as follows:

Years	1	2	3	4	5	6	7	8
Maintenance cost (Rs) $M(t)$	20	40	20	25	30	40	45	50
Resale value (Rs) $S(t)$	130	120	115	105	90	75	60	50

(Cost of money is zero.)

Required:

(i) Determine the average cost of the machine to date for each year.

(ii) Identify at what age the machine should be replaced on economic consideration.

Assuming the cost of money is zero.

Answer:

Years (t)	Maintenance Cost in ₹ M(t)	Cumulative Maintenance Cost in ₹ CM(t)	Resale Value in ₹ S(t)	C-S (t) in ₹ C=₹150	Total Cost T(t) = C-S(t) + C M(t)	Avg. Cost in ₹ G(t) = T(t)/t
1	20	20	130	20	40	40
2	40	60	120	30	90	45
3	40	100	80	70	150	38.333
4	25	105	105	45	150	37.5
5	30	135	90	60	195	39
6	40	175	75	75	250	41.666
7	45	220	60	90	310	44.286
8	50	270	50	100	370	46.25

Average cost is minimum at the end of the 4th year. Hence the machine may be replaced at the end of 4th year.

Question 5.**(Jun 23 5M)**

SONTECH Ltd., a Solar manufacturing company has observed the following number of breakdowns in the new Lantern over the past year:

No. of breakdowns	0	1	2	3
No. of months it occurred	3	6	2	1

It costs the company 2000 to rectify a lantern. For a cost of ₹ 600 per month, preventive maintenance

can be carried out to limit the breakdown to one per month.

Required:

Which policy is suitable for the company? Support your answer with needful calculations and justification.

Answer:

No. of breakdown (x)	Frequency in months (f)	Probability (p = f/Σf)	Expected no. of breakdowns (px)
0	3	0.25	0
1	6	0.5	0.5
2	2	0.167	0.334
3	1	0.083	0.249
Total	Σf = 12	Σp = 1	Σpx = 1.083

Expected breakdown cost per month: Expected no. of breakdown per month x cost of each Breakdown = $1.083 \times 2000 = 72166$

Preventive maintenance cost per month:

Average cost of one breakdown/month = 2000

Maintenance contract cost/month = 600

Total = 32600

For company SONTECH Ltd, breakdown maintenance is preferable as preventive maintenance costs more than breakdown maintenance

Question 6.**(Jun 23 9M)**

The management of Green In, Hotel is considering the periodic replacement of light bulbs fitted in its rooms. There are 500 rooms in the hotel and each room has 6 bulbs. The management of Green In Hotel is now following the policy of replacing the bulbs as they fail at a total cost of Rs.30 per bulb. The management feels that this cost can be reduced to Rs.10 by adopting the periodic replacement method.

The following mortality rate has been observed for the said light bulb:

Month of Use	1	2	3	4	5
Prob. of bulbs failing by the end of the month	0.10	0.15	0.25	0.30	0.20

Assume that the bulbs that fail during the month are replaced just before the end of that month.

Required:

- Compute the costs (in ₹) of Individual Replacement of bulbs per month.
- Present the Optimum Replacement cycle under Group Replacement.
- State best strategy for the Management of Green in Hotel to follow.
(Present calculation to the nearest integer).

Answer:

Months of use (x)	Prob. of bulb failing by the end of month (P)	PX
1	0.10	0.10
2	0.15	0.30
3	0.25	0.75
4	0.30	1.20
5	0.20	1.00
		$\Sigma P_i X_i = 3.35$ months

Total no. of bulbs = 500 × 6 = 3000 bulbs

Average no. of Replacement = $3000 / 3.35 = 896$ bulbs/month

Cost of Individual Replacement = $896 \times 30 = 826,880$ /month

(ii)

Let N_i be the no. of bulbs replaced at the end of i th month

$N_0 = 3000$, $P_1 = 0.10$, $P_2 = 0.15$, $P_3 = 0.25$, $P_4 = 0.30$, $P_5 = 0.20$

- $N_1 = N_0 P_1$

$$= 3000 \times 0.10 = 300$$

- $N_2 = N_0 P_2 + N_1 P_1$

$$= 3000 \times 0.15 + 300 \times 0.10 = 450 + 30 = 480$$

- $N_3 = N_0 P_3 + N_1 P_2 + N_2 P_1$

$$= 3000 \times 0.25 + 300 \times 0.15 + 480 \times 0.10$$

$$= 750 + 45 + 48 = 843$$

- $N_4 = N_0 P_4 + N_1 P_3 + N_2 P_2 + N_3 P_1$

$$= 3000 \times 0.30 + 300 \times 0.25 + 480 \times 0.15 + 843 \times 0.10$$

$$= 900 + 75 + 72 + 84.3$$

$$= 1131.3$$

- $N_5 = 3000 \times 0.20 + 300 \times 0.30 + 480 \times 0.25 + 843 \times 0.15 + 1131.3 \times 0.10$

$$= 600 + 90 + 120 + 126.45 + 113.13$$

$$= 1049.58$$

Computation of Average Cost:

Month (x)	Cumulative number of component replaced individually by month end	Cost Individual (₹)	Cost Group (₹)
1	300	9,000	30,000
2	780	23,400	30,000
3	1,623	48,690	30,000
4	2,754.3	82,629	30,000
5	3,803.88	1,14,116.4	30,000

Month (x)	Total Cost (Tc) (₹)	Average Cost = Tc/n (₹/month)
1	39,000	39,000
2	53,400	26,700
3	78,690	26,230
4	1,12,629	28,157.25
5	1,44,116.4	28,823.28

Since, the average cost is lowest in 3rd month the optimal interval i.e., replacement in 3 months (iii)

Average cost of Group Replacement = ₹ 26,230

Average cost of Individual Replacement = ₹ 26,880

Hence, the best strategy is to adopt Group Replacement.

Question 7.

(Dec 22 6M)

ANEX Ltd. an Engineering firm is using a machine whose purchase price is 813,000. The installation charges amount to 3,700 and the machine has a scrap value of only ₹ 1,400 because the firm has a monopoly of this type of work. The maintenance cost in various years as is shown below:

Year	1	2	3	4	5	6	7	8	9
Cost (₹)	300	850	1,300	1,900	2,600	3,300	4,200	6,000	7,500

Required:

(i) Determine after how many years should the machine be replaced on economic considerations (Assuming that machine replacement can be done only at the year end).

(ii) What will be the average cost of Replacement?

Answer:

(i) The machine may best be replaced every 7th year.

(ii) The average cost of Replacement is Rs. 4,250 approximately

MODULE 1. INTRODUCTION

Multiple Choice Questions (MCQs)

1. Which of the following best describes Operations Management (OM)?
 - (a) The management of financial resources in an organization.
 - (b) The management of marketing strategies in an organization.
 - (c) The management of the part of an organization responsible for producing goods and/or services.
 - (d) The management of human resources in an organization.
2. What does Operations Management (OM) encompass?
 - (a) Only the acquisition of raw materials.
 - (b) Only the conversion of raw materials into products.
 - (c) All organizational activities that acquire, process, and convert raw materials into consumable products and services.
 - (d) Only the distribution of finished products to customers.
3. Which of the following is NOT a focus of Operations Management?
 - (a) Product Design
 - (b) Process Design
 - (c) Quality Management
 - (d) Financial Auditing
4. What is the primary function of an Operating System in the context of resource configuration?
 - (a) To manage financial transactions
 - (b) To convert inputs into outputs
 - (c) To design marketing strategies
 - (d) To recruit employees
5. Which of the following best describes the role of physical resources in an Operating System?
 - (a) They are used to create outputs that satisfy customer wants
 - (b) They are used to manage customer relationships
 - (c) They are used to develop software applications
 - (d) They are used to conduct market research
6. What are the twin objectives of Operations Management?
 - (a) Customer Services and Financial Management
 - (b) Customer Services and Resources Utilization
 - (c) Resources Utilization and Marketing
 - (d) Financial Management and Marketing
7. Which of the following is NOT an aspect of customer service in Operations Management?
 - (a) Specification
 - (b) Cost
 - (c) Timing
 - (d) Marketing
8. What is the primary goal of customer service in Operations Management?
 - (a) To maximize profits
 - (b) To provide goods or services with the right specification, at the right cost, and at the right time
 - (c) To reduce operational costs
 - (d) To increase market share
9. Why is resource utilization important in Operations Management?

- (a) To increase marketing efforts
 - (b) To satisfy customer wants effectively
 - (c) To reduce employee turnover
 - (d) To enhance brand image
10. What can lead to the commercial failure of an operating system?
- (a) Efficient use of resources
 - (b) High customer satisfaction
 - (c) Inefficient use of resources or inadequate customer service
 - (d) Effective marketing strategies
11. Which aspect of customer service ensures that products meet the required standards?
- (a) Cost
 - (b) Specification
 - (c) Timing
 - (d) Marketing
12. How does Operations Management achieve effective operations?
- (a) Through efficient use of resources
 - (b) By increasing marketing budgets
 - (c) By hiring more employees
 - (d) By reducing product quality
13. What is the impact of providing goods or services at the right cost?
- (a) It increases operational complexity
 - (b) It enhances customer satisfaction
 - (c) It reduces product quality
 - (d) It decreases market share
14. What is the primary consideration in the manufacturing function of operations management?
- (a) Cost
 - (b) Timing
 - (c) Specification
 - (d) Marketing
15. Which of the following is a secondary consideration in transport management?
- (a) Specification
 - (b) Cost
 - (c) Quality
 - (d) Innovation
16. What is the primary goal of supply management in operations management?
- (a) To increase market share
 - (b) To meet the required specifications of materials
 - (c) To enhance brand image
 - (d) To reduce employee turnover
17. Which aspect of service management ensures that services meet customer expectations?
- (a) Cost
 - (b) Specification
 - (c) Timing
 - (d) Marketing
18. Why is timing important in operations management?

- (a) To increase operational complexity
 - (b) To ensure operations are completed within the required timeframe
 - (c) To reduce product quality
 - (d) To decrease market share
19. How does cost management contribute to operations management?
- (a) By increasing marketing budgets
 - (b) By ensuring operations are economical
 - (c) By hiring more employees
 - (d) By reducing product quality
20. Which of the following is a key consideration in the location of facilities?
- (a) Employee satisfaction
 - (b) Proximity to suppliers
 - (c) Product design
 - (d) Quality control
21. What is the primary goal of plant layout and material handling?
- (a) To increase product variety
 - (b) To minimize handling costs and reduce production time
 - (c) To enhance marketing strategies
 - (d) To improve employee training
22. Which activity involves creating a new product to meet customer needs?
- (a) Process Design
 - (b) Quality Control
 - (c) Product Design
 - (d) Maintenance Management
23. What does process design focus on?
- (a) Planning and decision-making regarding workflow, equipment, and technology
 - (b) Ensuring product quality
 - (c) Managing inventory levels
 - (d) Employee performance evaluation
24. Which function is responsible for managing the production process to ensure timely and quality output?
- (a) Production Planning and Control
 - (b) Materials Management
 - (c) Plant Layouts
 - (d) Location of Facilities
25. Quality control primarily involves:
- (a) Designing new products
 - (b) Regular inspections, testing, and monitoring of production processes
 - (c) Managing supplier relationships
 - (d) Planning facility locations
26. Which activity ensures that the right materials are available at the right time and in the right quantities?
- (a) Maintenance Management
 - (b) Materials Management
 - (c) Process Design

(d) Quality Control

27. What is the main objective of maintenance management?

- (a) To design new products
- (b) To ensure machinery and equipment operate efficiently and reliably
- (c) To manage inventory levels
- (d) To plan production schedules

28. Which of the following is NOT a part of operations management?

- (a) Location of Facilities
- (b) Marketing Strategies
- (c) Quality Control
- (d) Production Planning and Control

29. In the context of operations management, what does the term 'efficiency' refer to?

- (a) Meeting customer requirements
- (b) Using as few resources as needed
- (c) Increasing product variety
- (d) Enhancing employee satisfaction

30. Which term is traditionally used for systems where tangible goods are produced?

- (a) Operations Management
- (b) Production Management
- (c) Quality Control
- (d) Materials Management

31. In which context is operations management more frequently used?

- (a) Manufacturing physical products
- (b) Transforming inputs into intangible services
- (c) Designing new products
- (d) Managing supplier relationships

32. Which of the following best describes the historical evolution of the subject?

- (a) Operations management precedes production management
- (b) Production management is a modern term used today
- (c) Production management precedes operations management
- (d) Operations management is limited to manufacturing

33. Which example best illustrates operations management?

- (a) Assembling cars in a factory
- (b) Coordinating medical staff in a hospital
- (c) Designing a new smartphone
- (d) Managing inventory in a warehouse

34. Which of the following techniques is used to enhance efficiency and quality in modern manufacturing?

- (a) Total Quality Management (TQM)
- (b) Customer Relationship Management (CRM)
- (c) Social Media Marketing (SMM)
- (d) Human Resource Management (HRM)

35. What is a key characteristic of service-oriented production systems?

- (a) High volume production for global markets
- (b) Intangible and perishable nature of services
- (c) Focus on manufacturing physical goods

- (d) Minimal interaction with customers
36. What has contributed to the disappearance of traditional "smokestack" factories?
- (a) Increased demand for mass production
 - (b) Protective labour legislation and environmental movements
 - (c) Focus on large-scale industrialization
 - (d) Decline in technological advancements
37. Who advocated for smaller working units and community ownership in his book "Small is Beautiful"?
- (a) Henry Ford
 - (b) E.F. Schumacher
 - (c) Steve Jobs
 - (d) Elon Musk
38. Which of the following is an example of a company using Just-in-Time (JIT) to gain a competitive advantage?
- (a) Apple
 - (b) Toyota
 - (c) Microsoft
 - (d) Amazon
39. Why is the service sector gaining greater relevance in modern operations?
- (a) Because it involves high-volume production
 - (b) Due to the intangible and perishable nature of services
 - (c) Because it requires minimal customer interaction
 - (d) Due to the focus on physical goods production
40. What is a characteristic of modern factories compared to traditional ones?
- (a) They are more polluting
 - (b) They are aesthetically designed and environmentally friendly
 - (c) They focus solely on mass production
 - (d) They have minimal technological integration
41. Which concept opposes giant organizations and increased specialization?
- (a) Total Quality Management (TQM)
 - (b) Business Process Re-engineering (BPRE)
 - (c) Small is Beautiful
 - (d) Just-in-Time (JIT)
42. What is an example of a service-oriented production system?
- (a) A car manufacturing plant
 - (b) A hotel chain managing bookings and customer service
 - (c) A large-scale industrial factory
 - (d) A tech startup with a global production line
43. Which of the following is NOT a characteristic of modern operations functions?
- (a) Focus on gaining competitive advantage through production systems
 - (b) Emphasis on service orientation
 - (c) Disappearance of traditional "smokestack" factories
 - (d) Increased focus on mass production without customization
44. What has globalization compelled many manufacturing firms to do?
- (a) Increase local production
 - (b) Establish operations in multiple countries

- (c) Reduce product quality
- (d) Focus solely on domestic markets

45. Which company is known for aligning its production strategy with lean manufacturing principles?

- (a) Apple
- (b) Toyota
- (c) Amazon
- (d) Unilever

46. What is the primary goal of Total Quality Management (TQM)?

- (a) Increase production speed
- (b) Achieve customer satisfaction through continuous improvement
- (c) Reduce labor costs
- (d) Expand market share

47. Which company is an example of agile manufacturing due to its flexible supply chain?

- (a) Ford
- (b) Tesla
- (c) Zara
- (d) General Electric

48. What competitive advantage does reducing manufacturing cycle time provide?

- (a) Higher production costs
- (b) Quicker delivery times
- (c) Increased product defects
- (d) Lower employee satisfaction

49. Which company uses advanced robotics and automation in its manufacturing processes?

- (a) Motorola
- (b) Tesla
- (c) Walmart
- (d) Unilever

50. What is an example of worker involvement in operations management?

- (a) Centralized decision-making
- (b) Quality circles
- (c) Corporate downsizing
- (d) Outsourcing

51. What does re-engineering typically involve?

- (a) Minor adjustments to existing processes
- (b) Drastic measures to improve performance
- (c) Increasing workforce size
- (d) Reducing product quality

52. Which company has committed to reducing its environmental footprint by using sustainable materials?

- (a) Apple
- (b) Unilever
- (c) Ford
- (d) Amazon

53. What is the purpose of corporate downsizing?

- (a) Increase workforce size

- (b) Improve productivity and profitability
- (c) Expand market share
- (d) Enhance employee satisfaction

54. Which company is known for its efficient supply chain management practices?

- (a) General Electric
- (b) Walmart
- (c) Tesla
- (d) Ford

55. What is the main benefit of lean production systems?

- (a) High resource consumption
- (b) High volumes of high-quality goods
- (c) Increased production costs
- (d) Reduced product variety

56. Which company is an example of using lean production systems?

- (a) Apple
- (b) Toyota
- (c) Amazon
- (d) Unilever

57. What is a key characteristic of agile manufacturing?

- (a) Slow response to market changes
- (b) High flexibility in production
- (c) High production costs
- (d) Low product quality

58. Which company implemented TQM to improve product quality?

- (a) Motorola
- (b) Tesla
- (c) Ford
- (d) Amazon

59. What is the focus of supply chain management?

- (a) Increasing production costs
- (b) Reducing costs associated with transportation, warehousing, and distribution
- (c) Expanding workforce size
- (d) Enhancing product quality

60. Which company is known for its efficient logistics and delivery systems?

- (a) Apple
- (b) Amazon
- (c) Ford
- (d) Unilever

61. What is the goal of environmental initiatives in operations management?

- (a) Increase waste production
- (b) Reduce pollution and waste
- (c) Increase use of toxic chemicals
- (d) Decrease product quality

62. Which company re-engineered its accounts payable process to improve efficiency?

- (a) Toyota

- (b) Ford
- (c) Amazon
- (d) Walmart

63. What is a common outcome of corporate downsizing?

- (a) Increased workforce size
- (b) Improved productivity and profitability
- (c) Enhanced employee satisfaction
- (d) Expanded market share

Answers for MCQs

1.	c)	The management of the part of an organization responsible for producing goods and/or services.
2.	c)	All organizational activities that acquire, process, and convert raw materials into consumable products and services.
3.	d)	Financial Auditing
4.	b)	To convert inputs into outputs
5.	a)	They are used to create outputs that satisfy customer wants
6.	b)	Customer Services and Resources Utilization
7.	d)	Marketing
8.	b)	To provide goods or services with the right specification, at the right cost, and at the right time
9.	b)	To satisfy customer wants effectively
10.	c)	Inefficient use of resources or inadequate customer service
11.	b)	Specification
12.	a)	Through efficient use of resources
13.	b)	It enhances customer satisfaction
14.	c)	Specification
15.	b)	Cost
16.	b)	To meet the required specifications of materials
17.	b)	Specification
18.	b)	To ensure operations are completed within the required timeframe
19.	b)	By ensuring operations are economical
20.	b)	Proximity to suppliers
21.	b)	To minimize handling costs and reduce production time
22.	c)	Product Design
23.	a)	Planning and decision-making regarding workflow, equipment, and technology
24.	a)	Production Planning and Control
25.	b)	Regular inspections, testing, and monitoring of production processes
26.	b)	Materials Management
27.	b)	To ensure machinery and equipment operate efficiently and reliably
28.	b)	Marketing Strategies
29.	b)	Using as few resources as needed
30.	b)	Production Management
31.	b)	Transforming inputs into intangible services
32.	c)	Production management precedes operations management



33.	b)	Coordinating medical staff in a hospital
34.	a)	Total Quality Management (TQM)
35.	b)	Intangible and perishable nature of services
36.	b)	Protective labour legislation and environmental movements
37.	b)	E.F. Schumacher
38.	b)	Toyota
39.	b)	Due to the intangible and perishable nature of services
40.	b)	They are aesthetically designed and environmentally friendly
41.	c)	Small is Beautiful
42.	b)	A hotel chain managing bookings and customer service
43.	d)	Increased focus on mass production without customization
44.	b)	Establish operations in multiple countries
45.	b)	Toyota
46.	b)	Achieve customer satisfaction through continuous improvement
47.	c)	Zara
48.	b)	Quicker delivery times
49.	b)	Tesla
50.	b)	Quality circles
51.	b)	Drastic measures to improve performance
52.	b)	Unilever
53.	b)	Improve productivity and profitability
54.	b)	Walmart
55.	b)	High volumes of high-quality goods
56.	b)	Toyota
57.	b)	High flexibility in production
58.	a)	Motorola
59.	b)	Reducing costs associated with transportation, warehousing, and distribution
60.	b)	Amazon
61.	b)	Reduce pollution and waste
62.	b)	Ford
63.	b)	Improved productivity and profitability

MODULE 2 OPERATIONS PLANNING

Multiple Choice Questions (MCQs)

1. The act of assessing the future and making provisions for it is known as:
 - a) Planning
 - b) Assessment
 - c) Forecasting
 - d) Scheduling
2. The period of forecasting depends on:
 - a) The availability of data
 - b) The purpose for which the forecast is made
 - c) The size of the organization
 - d) The type of industry
3. Long range forecasting typically covers a period of:
 - a) One week
 - b) One month
 - c) Several years
 - d) One year
4. Which of the following is a purpose of long range forecasting?
 - a) Estimating inventory requirements
 - b) Planning for future manpower requirements
 - c) Determining budgetary control over expenses
 - d) Scheduling operations
5. Medium range forecasting usually spans a period of:
 - a) One week
 - b) One month
 - c) One to three years
 - d) Five years
6. Which of the following is a purpose of medium range forecasting?
 - a) Determining schedule of operations
 - b) Estimating cash flow from sales
 - c) Planning for research and development
 - d) Estimating inventory requirements
7. Short range forecasting covers a period of up to:
 - a) One week
 - b) One month
 - c) One year
 - d) Three years
8. Which of the following is a purpose of short range forecasting?
 - a) Planning for future manpower requirements
 - b) Determining budgetary control over expenses
 - c) Estimating inventory requirements
 - d) Planning for research and development
9. Long range forecasting is used for:
 - a) Operational planning

- b) Tactical planning
 - c) Strategic planning
 - d) Daily planning
10. Medium range forecasting is used for:
- a) Strategic planning
 - b) Tactical planning
 - c) Operational planning
 - d) Long-term planning
11. Short range forecasting is used for:
- a) Strategic planning
 - b) Tactical planning
 - c) Operational planning
 - d) Long-term planning
12. Which of the following is not a purpose of long range forecasting?
- a) Planning for material requirements
 - b) Determining schedule of operations
 - c) Planning for future manpower requirements
 - d) Estimating cash flow from sales
13. Which of the following is not a purpose of medium range forecasting?
- a) Determining budgetary control over expenses
 - b) Planning for capacity adjustments
 - c) Estimating inventory requirements
 - d) Determining dividend policy
14. Which of the following is not a purpose of short range forecasting?
- a) Estimating inventory requirements
 - b) Providing transport facilities for dispatch of finished goods
 - c) Planning for research and development
 - d) Deciding work loads for men and machines
15. The Delphi method is a structured communication technique that relies on:
- a) Historical data
 - b) Expert opinions
 - c) Mathematical models
 - d) Market surveys
16. Which method involves contacting actual users of the product to ask about their intention to buy in the future?
- a) Collective Opinion Method
 - b) Survey of Buyer's Intention Method
 - c) Group Executive Judgment Method
 - d) Market Test Method
17. The Survey of Buyer's Intention method is most suitable for:
- a) Long-run forecasting
 - b) Medium-run forecasting
 - c) Short-run forecasting
 - d) None of the above
18. Which method secures views from salesmen, branch managers, area managers, and sales managers?
- a) Expert's Opinion Method

- b) Survey of Buyer's Intention Method
- c) Collective Opinion Method
- d) Market Test Method

19. In the Collective Opinion method, who is required to estimate expected sales in their respective territories?

- a) Branch managers
- b) Salesmen
- c) Area managers
- d) Sales managers

20. Which method involves combining and averaging the opinions of top executives from different fields?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Method
- d) Market Test Method

21. The Expert's Opinion method collects opinions from:

- a) Internal sales teams
- b) Specialists outside the organization
- c) Top executives within the organization
- d) Customers directly

22. Which method is appropriate when the product is new in the market or good estimators are not available?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Method
- d) Market Test Method

23. Under the Market Test method, the seller sells the product in:

- a) .The entire market
- b) A part of the market
- c) International markets
- d) .Online platforms only

24. Which method involves analysing opinions given in newspapers and journals?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Expert's Opinion Method
- d) Market Test Method

25. The estimates of individual salesmen in the Collective Opinion method are:

- a) Ignored
- b) Consolidated
- c) Discarded
- d) Kept confidential

26. Which method is used to make sales forecasts based on the willingness of various customers?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Method
- d) Market Test Method

27. In the Group Executive Judgment method, opinions are sought from executives in:

- a) Marketing only
- b) Finance only
- c) Production only
- d) Different fields such as marketing, finance, and production

28. The Market Test method is quite appropriate when:

- a) The product is well-established
- b) Good estimators are available
- c) Buyers do not prepare their purchase plan
- d) The market is saturated

29. Which method involves securing views for different segments of the market?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Method
- d) Expert's Opinion Method

30. The Group Executive Judgment method is a process of:

- a) Directly contacting customers
- b) Combining, averaging, or evaluating opinions of top executives
- c) Selling products in a part of the market
- d) Collecting opinions from external specialists

31. Which method is used when the organization collects opinions from specialists in the field outside the organization?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Method
- d) Expert's Opinion Method

32. The Survey of Buyer's Intention method involves estimating total sales forecasts based on:

- a) Historical sales data
- b) Advice and willingness of various customer
- c) Opinions of top executives
- d) Market test results

33. In the Collective Opinion method, the estimates are further examined by:

- a) .Salesmen
- b) Customers
- c) Successive executive levels
- d) .External specialists

34. Which method is used to make sales forecasts by analysing the opinions and views of experts?

- a) Survey of Buyer's Intention Method
- b) Collective Opinion Method
- c) Group Executive Judgment Metho
- d) .Expert's Opinion Method

35. The Market Test method helps in making the assessment of sales for the full market based on:
- a) Historical sales data
 - b) Results of test sales
 - c) Opinions of top executives
 - d) Customer surveys
36. Which factor involves the availability of raw materials and natural resources?
- a) Markets
 - b) Sourcing
 - c) Cost
 - d) Environmental concerns
37. Proximity to market helps in:
- a) Reducing transportation costs
 - b) Increasing lease costs
 - c) Enhancing environmental concerns
 - d) Reducing skilled labor availability
38. Which factor includes lesser transportation costs and well-developed transportation modes?
- a) Sourcing
 - b) Market
 - c) Cost
 - d) Socio-cultural issues
39. A supportive community and familiarity with local culture fall under:
- a) Environmental concerns
 - b) Socio-cultural, community, and political issues
 - c) Cost
 - d) Markets
40. Which factor is crucial for maintaining productivity and innovation?
- a) Environmental concerns
 - b) Availability of skilled labor
 - c) Competitive pressure
 - d) Cost
41. The presence of competitors influences:
- a) Environmental concerns
 - b) Sourcing
 - c) Competitive pressure
 - d) Socio-cultural issues
42. Which factor involves the availability of medical facilities, fire, and police services?
- a) Markets
 - b) Cost
 - c) Socio-cultural, community, and political issues
 - d) Environmental concerns
43. Environmental concerns include:
- a) Air and water quality
 - b) Lease costs
 - c) Proximity to market
 - d) Availability of skilled labor
44. Which factor involves connectivity to alternate vendors?

- a) Market
- b) Sourcing
- c) Cost
- d) Environmental concerns

45. Proximity to key suppliers is a consideration under:

- a) Markets
- b) Cost
- c) Sourcing
- d) Socio-cultural issues

46. Lesser lease or rental costs fall under which factor?

- a) Markets
- b) Cost
- c) Sourcing
- d) Environmental concerns

47. The availability of prospective employees is a consideration under:

- a) Socio-cultural, community, and political issues
- b) Markets
- c) Cost
- d) Environmental concerns

48. Which factor includes the opportunity for cross-docking and utilizing milk vans?

- a) Markets
- b) Sourcing
- c) Cost
- d) Environmental concerns

49. Connectivity with a large customer base is a consideration under:

- a) Markets
- b) Cost
- c) Sourcing
- d) Environmental concerns

50. Statutory and regulatory rules and regulations fall under which factor?

- a) Markets
- b) Cost
- c) Socio-cultural, community, and political issues
- d) Environmental concerns

51. What is the primary goal of facility layout planning?

- a) To increase the number of machines
- b) To create an efficient physical arrangement of economic activity centres
- c) To reduce the number of employees
- d) To increase the size of the facility

52. Which type of layout groups similar processes or functions together?

- a) Product layout
- b) Fixed position layout
- c) Process layout
- d) Cellular manufacturing layout

53. In which layout does the product remain stationary while workers and equipment move to it?

- a) Product layout

- b) Fixed position layout
- c) Process layout
- d) Cellular manufacturing layout

54. Which layout is suitable for high-volume production of standardized products?

- a) Process layout
- b) Product layout
- c) Fixed position layout
- d) Cellular manufacturing layout

55. What is a key characteristic of a cellular manufacturing layout?

- a) It arranges equipment in a linear sequence
- b) It groups different machines into cells
- c) It keeps the product stationary
- d) It integrates elements of both process and product layouts

56. Which layout is often used in facilities that produce a variety of products with different production processes?

- a) Process layout
- b) Product layout
- c) Fixed position layout
- d) Mixed layout

57. What is the main focus of service facility layouts?

- a) Reducing production costs
- b) Bringing together customers and services
- c) Grouping similar machines together
- d) Arranging equipment in a linear sequence

58. Which type of layout is ideal for custom furniture workshops?

- a) Product layout
- b) Fixed position layout
- c) Process layout
- d) Mixed layout

59. In a product layout, how are machines arranged?

- a) In groups based on their functions
- b) In a linear sequence based on the production process
- c) Around a stationary product
- d) In cells for specific product families

60. Which layout is commonly used in aircraft manufacturing?

- a) Product layout
- b) Fixed position layout
- c) Process layout
- d) Cellular manufacturing layout

61. What is a key benefit of a mixed layout?

- a) It reduces the number of employees needed
- b) It integrates elements of both process and product layouts
- c) It keeps the product stationary
- d) It arranges equipment in a linear sequence

62. Which layout type is designed around customer receiving and servicing functions?

- a) Product layout

- b) Fixed position layout
- c) Service facility layout
- d) Cellular manufacturing layout

63. What is the main advantage of a product layout in a candy factory?

- a) It groups similar machines together
- b) It allows for high-volume production of standardized products
- c) It keeps the product stationary
- d) It integrates elements of both process and product layouts

64. Which layout type is used for large, bulky products like ships and aircraft?

- a) Product layout
- b) Fixed position layout
- c) Process layout
- d) Cellular manufacturing layout

65. What is a common feature of service facility layouts?

- a) Grouping similar machines together
- b) Arranging equipment in a linear sequence
- c) Providing easy access from freeways and busy thoroughfares
- d) Keeping the product stationary

66. What is the primary goal of aggregate planning?

- a) To increase production capacity
- b) To minimize costs while meeting demand
- c) To reduce the number of employees
- d) To expand physical facilities

67. Aggregate planning typically covers a time horizon of:

- a) 1 month to 3 months
- b) 3 months to 1 year
- c) 1 year to 3 years
- d) 3 years to 5 years

68. Which strategy involves hiring or laying off workers in response to changes in demand?

- a) Varying inventory levels
- b) Subcontracting
- c) Varying the size of the workforce
- d) Varying hours worked

69. What is the purpose of varying the hours worked in aggregate planning?

- a) To reduce inventory levels
- b) To maintain a stable workforce while adjusting to demand fluctuations
- c) To increase the number of employees
- d) To expand production facilities

70. Which strategy involves building up inventory during periods of low demand?

- a) Varying the size of the workforce
- b) Subcontracting
- c) Varying hours worked
- d) Varying inventory levels

71. Subcontracting is particularly useful when:

- a) Demand is predictable and stable
- b) A company has excess production capacity

- c) Demand is unpredictable or there is a sudden surge in demand
- d) Inventory levels are high

72. Which of the following is an example of subcontracting?

- a) Hiring seasonal workers during the holiday season
- b) Implementing overtime during peak production periods
- c) Outsourcing production to external vendors during a demand surge
- d) Building up inventory during off-peak seasons

73. Aggregate planning assumes that physical facilities are:

- a) Flexible and can be easily expanded
- b) Fixed for the planning period
- c) Constantly changing
- d) Not considered in the planning process

74. What is the primary goal of Material Requirement Planning (MRP)?

- a) To increase production capacity
- b) To determine the quantity and timing for acquiring dependent demand items
- c) To reduce the number of employees
- d) To expand physical facilities

75. Which of the following is an objective of MRP?

- a) Increasing inventory levels
- b) Reducing manufacturing and delivery lead times
- c) Decreasing production efficiency
- d) Extending delivery deadlines

76. How does MRP help in inventory reduction?

- a) By ordering materials in bulk
- b) By determining the exact quantities needed and timing their procurement
- c) By storing large quantities of materials
- d) By delaying material orders

77. What benefit does MRP provide to marketing teams?

- a) It increases production costs
- b) It provides timely information about likely delivery times
- c) It reduces the number of products available
- d) It complicates the production schedule

78. Which of the following is NOT an objective of MRP?

- a) Inventory reduction
- b) Increased efficiency
- c) Realistic delivery commitments
- d) Increasing lead times

79. How does MRP increase production efficiency?

- a) By creating a backlog of orders
- b) By ensuring a continuous flow of materials through the production line
- c) By reducing the number of work centers
- d) By increasing idle time

80. What is the primary purpose of Manufacturing Resource Planning (MRP II)?

- a) To increase the number of employees
- b) To facilitate planning and control of manufacturing processes and support functions
- c) To reduce the size of the manufacturing facility

- d) To eliminate the need for financial planning
81. Which of the following is NOT a component of MRP II?
- Materials planning
 - Capacity planning
 - Financial planning
 - Customer relationship management
82. How does MRP II enhance sales and marketing coordination?
- By eliminating the need for sales forecasts
 - By providing accurate delivery commitments based on production schedules
 - By increasing inventory levels
 - By reducing the number of sales staff
83. What is a key difference between MRP I and MRP II?
- MRP I includes financial planning, while MRP II does not
 - MRP II integrates additional data such as capacity and financial needs
 - MRP I is used for sales and marketing coordination, while MRP II is not
 - MRP II eliminates the need for materials planning

Key:

1.	c)	Forecasting
2.	b)	The purpose for which the forecast is made
3.	c)	Several years
4.	b)	Planning for future manpower requirements
5.	c)	One to three years
6.	a)	Determining schedule of operations
7.	c)	One year
8.	c)	Estimating inventory requirements
9.	c)	Strategic planning
10.	b)	Tactical planning
11.	c)	Operational planning
12.	b)	Determining schedule of operations
13.	c)	Estimating inventory requirements
14.	c)	Planning for research and development
15.	b)	Expert opinions
16.	b)	Survey of Buyer's Intention Method
17.	c)	Short-run forecasting
18.	c)	Collective Opinion Method
19.	b)	Salesmen
20.	c)	Group Executive Judgment Method
21.	b)	Specialists outside the organization
22.	d)	Market Test Method
23.	b)	A part of the market
24.	c)	Expert's Opinion Method
25.	b)	Consolidated
26.	a)	Survey of Buyer's Intention Method
27.	d)	Different fields such as marketing, finance, and production
28.	c)	Buyers do not prepare their purchase plan

29.	b)	Collective Opinion Method
30.	b)	Combining, averaging, or evaluating opinions of top executives
31.	d)	Expert's Opinion Method
32.	b)	Advice and willingness of various customers
33.	c)	Successive executive levels
34.	d)	Expert's Opinion Method
35.	b)	Results of test sales
36.	b)	Sourcing
37.	a)	Reducing transportation costs
38.	c)	Cost
39.	b)	Socio-cultural, community, and political issues
40.	b)	Availability of skilled labor
41.	c)	Competitive pressure
42.	c)	Socio-cultural, community, and political issues
43.	a)	Air and water quality
44.	b)	Sourcing
45.	c)	Sourcing
46.	b)	Cost
47.	a)	Socio-cultural, community, and political issues
48.	b)	Sourcing
49.	a)	Markets
50.	c)	Socio-cultural, community, and political issues
51.	b)	To create an efficient physical arrangement of economic activity centres
52.	c)	Process layout
53.	b)	Fixed position layout
54.	b)	Product layout
55.	b)	It groups different machines into cells
56.	d)	Mixed layout
57.	b)	Bringing together customers and services
58.	c)	Process layout
59.	b)	In a linear sequence based on the production process
60.	b)	Fixed position layout
61.	b)	It integrates elements of both process and product layouts
62.	c)	Service facility layout
63.	b)	It allows for high-volume production of standardized products
64.	b)	Fixed position layout
65.	c)	Providing easy access from freeways and busy thoroughfares
66.	b)	To minimize costs while meeting demand
67.	b)	3 months to 1 year
68.	c)	Varying the size of the workforce
69.	b)	To maintain a stable workforce while adjusting to demand fluctuations
70.	d)	Varying inventory levels
71.	c)	Demand is unpredictable or there is a sudden surge in demand
72.	c)	Outsourcing production to external vendors during a demand surge

73.	b)	Fixed for the planning period
74.	b)	To determine the quantity and timing for acquiring dependent demand items
75.	b)	Reducing manufacturing and delivery lead times
76.	b)	By determining the exact quantities needed and timing their procurement
77.	b)	It provides timely information about likely delivery times
78.	d)	Increasing lead times
79.	b)	By ensuring a continuous flow of materials through the production line
80.	b)	To facilitate planning and control of manufacturing processes and support functions
81.	d)	Customer relationship management
82.	b)	By providing accurate delivery commitments based on production schedules
83.	b)	MRP II integrates additional data such as capacity and financial needs

MODULE 3. DESIGNING OF OPERATIONAL SYSTEM AND CONTROL

Multiple Choice Questions (MCQs)

1. What is the primary purpose of product design?
 - a) To increase production costs
 - b) To establish detailed characteristics of the product
 - c) To reduce market demand
 - d) To complicate the production process
2. Which of the following is an example of an augmented feature in a product?
 - a) The ability of a smartphone to make calls
 - b) The camera quality of a smartphone
 - c) The processor type in a laptop
 - d) The battery life of a remote control
3. How does product design influence production systems?
 - a) By increasing the number of defects
 - b) By providing a guideline for efficient production
 - c) By complicating the manufacturing process
 - d) By reducing the need for quality control
4. What is a core feature of a product?
 - a) An additional service provided with the product
 - b) The primary function of the product
 - c) The packaging of the product
 - d) The marketing strategy for the product
5. Why is it important to align product design with market demand?
 - a) To increase production costs
 - b) To ensure the product meets customer needs
 - c) To complicate the design process
 - d) To reduce the product's functionality
6. Which company is known for its lean manufacturing system based on efficient product design?
 - a) Apple
 - b) Tesla
 - c) Toyota
 - d) Nike
7. What does the mnemonic CTGI stand for in the context of product design?
 - a) Characteristics, Technical requirements, Guideline for production, Impetus to strategy
 - b) Cost, Time, Growth, Innovation
 - c) Customer, Technology, Goals, Implementation
 - d) Core, Technical, General, Important
8. Which of the following is an example of an augmented feature in a product?
 - a) The ability of a smartphone to make calls
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 - c) The processor type in a laptop
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 - a) Characteristics, Technical requirements, Guideline for production, Impetus to strategy
 - b) Cost, Time, Growth, Innovation
 - c) Customer, Technology, Goals, Implementation
 - d) Core, Technical, General, Important
13. How do product designers differentiate existing products?
 - a) By reducing the product's functionality
 - b) By incorporating innovative features
 - c) By increasing production costs
 - d) By complicating the design process
14. What is the importance of understanding customer requirements in product design?
 - a) To increase production costs
 - b) To ensure the product meets customer needs
 - c) To complicate the design process
 - d) To reduce the product's functionality
15. How do product designers contribute to the development of new products?
 - a) By brainstorming innovative ideas
 - b) By reducing the product's functionality
 - c) By increasing production costs
 - d) By complicating the design process
16. Which industry heavily relies on prototype testing to ensure safety and performance before mass production?
 - a) Fashion
 - b) Aerospace
 - c) Food and Beverage
 - d) Retail
17. What is the primary goal of documenting design specifications in product design?
 - a) To increase production costs
 - b) To ensure consistent manufacturing
 - c) To complicate the production process

- d) To reduce product quality
18. How does product design help in cost optimization?
- By increasing the complexity of the product
 - By creating efficient designs that reduce production costs
 - By ignoring customer feedback
 - By using expensive materials
19. Which company is known for its innovative bagless vacuum cleaner technology?
- Samsung
 - Dyson
 - Sony
 - Medtronic
20. What is the role of product designers in setting quality goals?
- To reduce the quality of the product
 - To provide critical inputs for ensuring high standards
 - To complicate the quality assurance process
 - To ignore regulatory standards
21. Which company is known for designing cost-effective and easy-to-assemble furniture?
- Nestlé
 - Boeing
 - IKEA
 - Toyota
22. What is a key method modern designers use to discover latent customer needs?
- Surveys
 - Social media analytics
 - Focus groups
 - Direct interviews
23. Why is user-friendliness important in product design?
- It increases production costs
 - It attracts people from various demographic backgrounds
 - It complicates the design process
 - It reduces product functionality
24. What does balancing form, function, and cost in product design ensure?
- Higher production costs
 - An appropriate balance between economies of scale and scope
 - Reduced product quality
 - Increased complexity in design
25. Which industry relies heavily on the quality of raw materials for product design?
- Automotive
 - Food
 - Electronics
 - Fashion
26. What is the impact of process and layout design on product design?
- It increases waste
 - It ensures efficient production
 - It complicates the manufacturing process

d) It reduces product quality

27. Why is the quality of machines and instruments important in product design?

- a) It increases production costs
- b) It affects the product's quality
- c) It complicates the design process
- d) It reduces the need for skilled labor

28. What does the capability and maturity of processes ensure in product design?

- a) Inconsistent product quality
- b) Reliable and consistent product quality
- c) Increased production costs
- d) Reduced product functionality

29. How do skilled resource persons contribute to product design?

- a) By increasing production costs
- b) By providing expertise for innovative designs
- c) By complicating the design process
- d) By reducing product quality

30. What is the effect of new product designs on existing products?

- a) They should complement and enhance existing products
- b) They should replace existing products
- c) They should reduce the functionality of existing products
- d) They should complicate the product line

31. Why is presentation and packaging important in product design?

- a) It increases production costs
- b) It attracts customers
- c) It complicates the design process
- d) It reduces product functionality

32. Which company is known for using social media analytics to identify customer preferences in the fashion industry?

- a) Nike
- b) Zara
- c) Samsung
- d) Whirlpool

33. What is a key factor in ensuring the quality of pharmaceuticals during the design process?

- a) Cost reduction
- b) State-of-the-art equipment
- c) Simplified design
- d) Reduced testing

34. What is a key characteristic of good product design in terms of customer satisfaction?

- a) High production costs
- b) Meeting customer needs and providing optimum value
- c) Complicated user interface
- d) Limited functionality

35. Why is reliability important in product design?

- a) It increases production costs
- b) It ensures the product is worthy of the price paid by customers

- c) It complicates the design process
- d) It reduces product functionality

36. What does cost-effectiveness in product design ensure?

- a) Higher production costs
- b) Affordable pricing for target customers
- c) Reduced product quality
- d) Increased complexity in design

37. Which company is known for its short design-to-market lead time in the fashion industry?

- a) Nike
- b) Zara
- c) Samsung
- d) L'Oréal

38. Why are aesthetics important in product design?

- a) They increase production costs
- b) They create an immediate impression in the minds of customers
- c) They complicate the design process
- d) They reduce product functionality

39. What is a key factor in ensuring user-friendliness in product design?

- a) High production costs
- b) Compatibility and ease of use
- c) Complicated user interface
- d) Limited functionality

40. Why is maintainability important in product design?

- a) It increases production costs
- b) It ensures the product is easy to maintain and reproduce
- c) It complicates the design process
- d) It reduces product functionality

41. What does balancing standardized and customized features in product design achieve?

- a) Higher production costs
- b) A mix of basic and personalized features
- c) Reduced product quality
- d) Increased complexity in design

42. Why are detailed specifications important in product design?

- a) They increase production costs
- b) They ensure the product meets all design and performance requirements
- c) They complicate the design process
- d) They reduce product functionality

43. What is a key consideration for safety in product design?

- a) High production costs
- b) Ensuring the product is safe to use and environmentally friendly
- c) Complicated user interface
- d) Limited functionality

44. Which company is known for designing cost-effective and stylish furniture?

- a) Nestlé
- b) Boeing

- c) IKEA
- d) Toyota

45. What is the impact of aesthetics on product design in the cosmetics industry?

- a) Increased production costs
- b) Enhanced product appeal through attractive packaging
- c) Complicated design process
- d) Reduced product functionality

46. Which process type is characterized by low volume and high variety?

- a) Batch process
- b) Job shop process
- c) Repetitive process
- d) Continuous process

47. What is a key characteristic of batch processing?

- a) High volume, low variety
- b) Low volume, high variety
- c) Moderate volume and variety
- d) Very high volume, highly standardized

48. Which industry commonly uses a repetitive process?

- a) Food industry
- b) Automotive industry
- c) Construction industry
- d) Petroleum industry

49. What is the main advantage of a continuous process?

- a) High customization
- b) Low equipment utilization
- c) High volume, standardized production
- d) Intermittent processing

50. Which process type is most suitable for producing custom furniture?

- a) Batch process
- b) Job shop process
- c) Repetitive process
- d) Continuous process

51. What is a common example of a product made using a batch process?

- a) Automobiles
- b) Ice cream
- c) Steel
- d) Software

52. Which process type involves a high degree of job customization and substantial resources?

- a) Batch process
- b) Job shop process
- c) Project process
- d) Continuous process

53. What is a key characteristic of the repetitive process?

- a) High flexibility of equipment
- b) Low labour skills

- c) High customization
- d) Intermittent processing

54. Which industry is an example of using a continuous process?

- a) Fashion industry
- b) Petroleum industry
- c) Electronics industry
- d) Food industry

55. What is the main focus of a project process?

- a) High volume production
- b) Standardized goods
- c) Customization and large scope
- d) Repetitive tasks

56. What is a key characteristic of the introduction phase of the product life cycle?

- a) High sales volume
- b) Low promotional expenditure
- c) High promotional expenditure
- d) High profit margins

57. During which phase of the product life cycle do companies focus on rapid revenue generation?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

58. What happens to sales volume during the maturity phase?

- a) It decreases rapidly
- b) It stabilizes
- c) It increases rapidly
- d) It remains constant

59. Which phase is characterized by market saturation and intense competition?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

60. What is a common strategy during the decline phase?

- a) Increase promotional expenditure
- b) Focus on cost consolidation
- c) Rapid revenue generation
- d) Market expansion

61. In which phase do companies often introduce product variations to maintain interest?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

62. What is the primary focus during the introduction phase?

- a) Maximizing profit margins
- b) Building product awareness

- c) Reducing production costs
- d) Expanding market share

63. Which phase involves significant investment in promotional campaigns?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

64. What happens to profit margins during the decline phase?

- a) They increase
- b) They stabilize
- c) They decrease
- d) They remain constant

65. Which phase is characterized by high consumer awareness but declining interest?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

66. What is a key objective during the growth phase?

- a) Reducing promotional expenditure
- b) Covering fixed costs and reducing overheads
- c) Discontinuing the product
- d) Introducing new product variations

67. Which phase often requires aggressive promotional and pricing programs?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

68. What is a common characteristic of the decline phase?

- a) Increasing sales volume
- b) High profit margins
- c) Decreasing sales volume
- d) High promotional expenditure

69. During which phase do companies focus on holding existing customers and creating new ones?

- a) Introduction
- b) Growth
- c) Maturity
- d) Decline

70. What is a key focus during the maturity phase to slow down the movement toward decline?

- a) Rapid revenue generation
- b) Product differentiation and variety
- c) High promotional expenditure
- d) Cost consolidation

71. What is the primary objective of the empathize stage in design thinking?

- a) To generate a wide range of ideas
- b) To gain a deep understanding of users' needs

- c) To build tangible prototypes
- d) To test solutions with real users

72. Which company used design thinking to create the "Keep the Change" program?

- a) Airbnb
- b) GE Healthcare
- c) Bank of America
- d) Procter & Gamble

73. What is the main focus of the ideate stage in design thinking?

- a) To define the core problems
- b) To build prototypes
- c) To generate creative ideas
- d) To test solutions

74. Which company improved their product by creating the "Adventure Series" MRI machines?

- a) UberEATS
- b) GE Healthcare
- c) Procter & Gamble
- d) Bank of America

75. What is the purpose of the prototype stage in design thinking?

- a) To test solutions with real users
- b) To generate a wide range of ideas
- c) To build tangible models of ideas
- d) To define the core problems

76. Which company used design thinking to refine their food delivery service?

- a) Airbnb
- b) GE Healthcare
- c) UberEATS
- d) Procter & Gamble

77. What is the final stage of the design thinking process?

- a) Empathize
- b) Define
- c) Ideate
- d) Test

Key:

1.	b)	To establish detailed characteristics of the product
2.	b)	The camera quality of a smartphone
3.	b)	By providing a guideline for efficient production
4.	b)	The primary function of the product
5.	b)	To ensure the product meets customer needs
6.	c)	Toyota
7.	b)	To establish detailed characteristics of the product
8.	b)	The camera quality of a smartphone
9.	b)	By providing a guideline for efficient production
10.	b)	To ensure the product meets customer needs
11.	c)	Toyota
12.	a)	Characteristics, Technical requirements, Guideline for production, Impetus to strategy
13.	b)	By incorporating innovative features

14.	b)	To ensure the product meets customer needs
15.	a)	By brainstorming innovative ideas
16.	b)	Aerospace
17.	b)	To ensure consistent manufacturing
18.	b)	By creating efficient designs that reduce production costs
19.	b)	Dyson
20.	b)	To provide critical inputs for ensuring high standards
21.	c)	IKEA
22.	b)	Social media analytics
23.	b)	It attracts people from various demographic backgrounds
24.	b)	An appropriate balance between economies of scale and scope
25.	b)	Food
26.	b)	It ensures efficient production
27.	b)	It affects the product's quality
28.	b)	Reliable and consistent product quality
29.	b)	By providing expertise for innovative designs
30.	a)	They should complement and enhance existing products
31.	b)	It attracts customers
32.	b)	Zara
33.	b)	State-of-the-art equipment
34.	b)	Meeting customer needs and providing optimum value
35.	b)	It ensures the product is worthy of the price paid by customers
36.	b)	Affordable pricing for target customers
37.	b)	Zara
38.	b)	They create an immediate impression in the minds of customers
39.	b)	Compatibility and ease of use
40.	b)	It ensures the product is easy to maintain and reproduce
41.	b)	A mix of basic and personalized features
42.	b)	They ensure the product meets all design and performance requirements
43.	b)	Ensuring the product is safe to use and environmentally friendly
44.	c)	IKEA
45.	b)	Enhanced product appeal through attractive packaging
46.	b)	Job shop process
47.	c)	Moderate volume and variety
48.	b)	Automotive industry
49.	c)	High volume, standardized production
50.	b)	Job shop process
51.	b)	Ice cream
52.	c)	Project process
53.	b)	Low labour skills
54.	b)	Petroleum industry
55.	c)	Customization and large scope
56.	c)	High promotional expenditure
57.	b)	Growth
58.	b)	It stabilizes
59.	c)	Maturity
60.	b)	Focus on cost consolidation
61.	c)	Maturity
62.	b)	Building product awareness
63.	a)	Introduction

64.	c)	They decrease
65.	d)	Decline
66.	b)	Covering fixed costs and reducing overheads
67.	c)	Maturity
68.	c)	Decreasing sales volume
69.	b)	Growth
70.	b)	Product differentiation and variety
71.	b)	To gain a deep understanding of users' needs
72.	c)	Bank of America
73.	c)	To generate creative ideas
74.	b)	GE Healthcare
75.	c)	To build tangible models of ideas
76.	c)	UberEATS
77.	d)	Test

MODULE 4. APPLICATION OF OPERATION RESEARCH - PRODUCTION PLANNING AND CONTROL

Multiple Choice Questions (MCQs):

1. Operations research helps in forecasting:
 - a) Income and expenditure
 - b) Weather patterns
 - c) Animal populations
 - d) Geological surveys
2. National planning and budgeting involve:
 - a) Scheduling major projects
 - b) Launching new social media platforms
 - c) Writing novels
 - d) Designing fashion collections
3. In defence service operations, operations research assists in:
 - a) Designing civilian architecture
 - b) Optimizing cost and time
 - c) Growing organic vegetables
 - d) Composing symphonies
4. Which company uses operations research for plant location optimization?
 - a) Tesla
 - b) Tata Steel
 - c) Facebook
 - d) Amazon
5. Operations research helps R&D departments by:
 - a) Creating marketing campaigns
 - b) Forecasting technology trends
 - c) Developing culinary recipes
 - d) Organizing music festivals
6. In business management, operations research assists in:
 - a) Playing video games
 - b) Strategy formation
 - c) Painting portraits
 - d) Knitting sweaters
7. How does operations research optimize irrigation projects?
 - a) By constructing amusement parks
 - b) By determining the best locations for supply points
 - c) By managing concert tours
 - d) By developing skincare products
8. Operations research helps in determining:
 - a) National education policies
 - b) Social media trends

- c) Video game scores
- d) Cinematic plotlines

9. Public works projects benefit from operations research by:

- a) Reducing project costs
- b) Increasing movie revenues
- c) Designing fashion lines
- d) Writing software codes

10. Which sector uses operations research for threat analysis?

- a) Education
- b) Defence
- c) Entertainment
- d) Agriculture

11. Operations research aids businesses in:

- a) Selecting areas of operation
- b) Publishing novels
- c) Composing music
- d) Arranging art exhibitions

12. Operations research is used in the construction of:

- a) Theme parks
- b) Major dams
- c) Personal blogs
- d) Art galleries

13. Operations research assists in:

- a) Forecasting income
- b) Designing fashion accessories
- c) Mixing music tracks
- d) Baking cakes

14. Inventory control in industrial fields is optimized through:

- a) Social media marketing
- b) Operations research
- c) Creative writing
- d) Film direction

15. Operations research in R&D helps with:

- a) Fashion trends
- b) Project management
- c) Cooking recipes
- d) Gardening techniques

16. Business strategy formation is aided by:

- a) Social media analysis
- b) Operations research
- c) Artistic expression
- d) Culinary arts

17. In agriculture, operations research determines:

- a) Supply points of inputs
- b) Movie release dates

- c) Social media likes
- d) Personal goals

18. Education planning uses operations research for:

- a) Student-teacher ratios
- b) Film editing
- c) Architectural design
- d) Event planning

19. Public works projects rely on operations research for:

- a) Estimating project timelines
- b) Writing music
- c) Painting techniques
- d) Crafting jewelry

20. Operations research helps in:

- a) Budget preparation
- b) Organizing events
- c) Launching products
- d) Creating digital art

21. The primary concern of PPC is:

- a) Marketing
- b) Delivery of products
- c) Financial planning
- d) Employee training

22. PPC contributes to the profits of an enterprise by:

- a) Reducing employee salaries
- b) Enhancing product delivery schedules
- c) Increasing marketing budgets
- d) Downsizing departments

23. Analyzing orders in PPC helps determine:

- a) Marketing strategies
- b) Raw materials needed
- c) Company mission statements
- d) Employee benefits

24. Supporting HR in PPC involves:

- a) Manpower planning
- b) Designing marketing campaigns
- c) Conducting customer surveys
- d) Developing financial policies

25. Controlling the stock of finished products ensures:

- a) Product design changes
- b) Overproduction avoidance
- c) Marketing innovation
- d) Staff reductions

26. Issuing requisitions in PPC pertains to:

- a) Financial audits
- b) Customer service calls

- c) Material purchase
- d) Event planning

27. Preparing route sheets and schedules in PPC is crucial for:

- a) Employee engagement
- b) Sequence of operations
- c) Marketing campaigns
- d) Customer surveys

28. Evaluating progress in PPC helps in:

- a) Financial planning
- b) Corrective actions
- c) Market analysis
- d) Product packaging

29. Revising production plans in PPC is necessary when:

- a) There are rush orders
- b) New products are launched
- c) Marketing strategies change
- d) Employee training is updated

30. Notifying sales and accounting in PPC involves:

- a) Production feasibility
- b) Marketing campaigns
- c) Staff training
- d) Customer surveys

31. Which function of production control involves laying down the path for work to follow?

- a) Planning
- b) Routing
- c) Scheduling
- d) Dispatching

32. The primary goal of production control is to:

- a) Reduce marketing costs
- b) Ensure timely delivery of products
- c) Enhance employee training
- d) Increase financial audits

33. Dispatching in production control refers to:

- a) Planning production operations in detail
- b) Issuing necessary orders to ensure schedules are met
- c) Laying down the path for work to follow
- d) Conducting occasional check-ups

34. Followup in production control is crucial for:

- a) Determining the necessary tools for production
- b) Checking whether work proceeds according to plans
- c) Marketing products to customers
- d) Designing product packaging

35. Which company uses JIT production methods involving meticulous scheduling?

- a) Nike
- b) Toyota

- c) Ford
- d) Amazon

36. Inspection in production control ensures:

- a) Increased production costs
- b) High quality of manufactured products
- c) Reduced employee engagement
- d) Increased marketing efforts

37. In Amazon's fulfillment centers, dispatching involves:

- a) Issuing orders for picking, packing, and shipping
- b) Planning production operations in detail
- c) Conducting occasional check-ups of products
- d) Laying down the path for work to follow

38. Which type of production control is most prominent in textiles and book printing?

- a) Flow control
- b) Load control
- c) Block control
- d) Order control

39. Flow control is commonly applied in industries like:

- a) Textiles
- b) Chemicals
- c) Aerospace
- d) Education

40. Load control is typically found in manufacturing processes with:

- a) Multiple production lines
- b) High-quality control
- c) Bottleneck machines
- d) Rapid product changes

41. Order control is most commonly employed in:

- a) Continuous production systems
- b) Job-lot shops
- c) Large-scale construction projects
- d) Food processing

42. Special project control is necessary in:

- a) Textile production
- b) Intermittent production systems
- c) Construction of bridges and buildings
- d) Batch production of food

43. Batch control is frequently found in:

- a) Textile manufacturing
- b) Automotive assembly
- c) Food processing
- d) Aerospace engineering

44. Which company uses flow control for continuous production of petroleum products?

- a) Tata Steel
- b) Indian Oil Corporation

- c) Arvind Limited
- d) Mahindra & Mahindra

45. Which type of control is employed by Hindustan Aeronautics Limited for custom orders?

- a) Batch control
- b) Flow control
- c) Load control
- d) Order control

46. Time study aims at:

- a) Designing new products
- b) Determining the best manner of doing a job
- c) Marketing strategies
- d) Financial planning

47. Work study focuses on:

- a) Using the available resources efficiently
- b) Designing new office spaces
- c) Creating marketing campaigns
- d) Writing company policies

48. Method study is the systematic investigation of:

- a) Financial transactions
- b) The existing method of doing a job
- c) Customer feedback
- d) Market trends

49. The main goal of method study is to:

- a) Increase employee salaries
- b) Develop an easier, rapid, efficient procedure
- c) Design new products
- d) Enhance marketing efforts

50. An example of time study application is:

- a) Optimizing assembly line processes at Maruti Suzuki
- b) Designing fashion accessories at a boutique
- c) Conducting market research for a new product
- d) Writing a novel

51. What is the primary purpose of scheduling in production planning?

- a) Designing new products
- b) Determining start and completion times for operations
- c) Hiring new employees
- d) Marketing products

52. Scheduling helps to:

- a) Increase marketing budget
- b) Engage machines and operators efficiently
- c) Design new office spaces
- d) Conduct customer surveys

53. After which function does scheduling come in production planning and control?

- a) Inspection
- b) Routing

- c) Dispatching
- d) Planning

54. Lean operations aim to eliminate which type of waste?

- a) Marketing costs
- b) Time, investment, and idle workers
- c) Product development costs
- d) Office supplies

55. Which company is known for implementing just-in-time inventory management to reduce investment waste?

- a) Apple
- b) Tesla
- c) Dell
- d) Amazon

56. Value stream mapping in lean operations is used to:

- a) Design new products
- b) Analyze the flow of materials and information
- c) Train employees
- d) Conduct market research

57. What is one of the key goals of JIT manufacturing?

- a) Increase inventory levels
- b) Reduce inventory levels
- c) Extend lead times
- d) Use multiple suppliers for every part

58. How does JIT improve quality?

- a) By outsourcing all quality checks
- b) By integrating quality checks at every production stage
- c) By increasing production speed
- d) By reducing the number of suppliers

59. Which company uses JIT to reduce lead times in fast fashion production?

- a) Apple
- b) Zara
- c) Amazon
- d) Tesla

60. JIT gives buying organizations more power in buyer-supplier relationships by:

- a) Using multiple suppliers for each part
- b) Limiting the number of suppliers to a select few
- c) Reducing quality requirements
- d) Increasing inventory levels

61. Continuous improvement in JIT involves:

- a) Correcting existing problems and identifying new ones
- b) Increasing the number of suppliers
- c) Extending lead times
- d) Decreasing product quality

62. Which company uses JIT to reduce lead times in fast fashion production?

- a) Apple

- b) Zara
- c) Amazon
- d) Tesla

63. JIT gives buying organizations more power in buyer-supplier relationships by:

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- d) Increasing inventory levels

64. Continuous improvement in JIT involves:

- a) Correcting existing problems and identifying new ones
- b) Increasing the number of suppliers
- c) Extending lead times
- d) Decreasing product quality

65. Total preventive maintenance in JIT aims to:

- a) Reduce setup times
- b) Minimize equipment breakdowns
- c) Increase lead times
- d) Decrease the number of employees

Key:

1.	a)	Income and expenditure
2.	a)	Scheduling major projects
3.	b)	Optimizing cost and time
4.	b)	Tata Steel
5.	b)	Forecasting technology trends
6.	b)	Strategy formation
7.	b)	By determining the best locations for supply points
8.	a)	National education policies
9.	a)	Reducing project costs
10.	b)	Defence
11.	a)	Selecting areas of operation
12.	b)	Major dams
13.	a)	Forecasting income
14.	b)	Operations research
15.	b)	Project management
16.	b)	Operations research
17.	a)	Supply points of inputs
18.	a)	Student-teacher ratios
19.	a)	Estimating project timelines
20.	a)	Budget preparation
21.	b)	Delivery of products
22.	b)	Enhancing product delivery schedules
23.	b)	Raw materials needed
24.	a)	Manpower planning
25.	b)	Overproduction avoidance

26.	c)	Material purchase
27.	b)	Sequence of operations
28.	b)	Corrective actions
29.	a)	There are rush orders
30.	a)	Production feasibility
31.	b)	Routing
32.	b)	Ensure timely delivery of products
33.	b)	Issuing necessary orders to ensure schedules are met
34.	b)	Checking whether work proceeds according to plans
35.	b)	Toyota
36.	b)	High quality of manufactured products
37.	a)	Issuing orders for picking, packing, and shipping
38.	c)	Block control
39.	b)	Chemicals
40.	c)	Bottleneck machines
41.	b)	Job-lot shops
42.	c)	Construction of bridges and buildings
43.	c)	Food processing
44.	b)	Indian Oil Corporation
45.	d)	Order control
46.	b)	Determining the best manner of doing a job
47.	a)	Using the available resources efficiently
48.	b)	The existing method of doing a job
49.	b)	Develop an easier, rapid, efficient procedure
50.	a)	Optimizing assembly line processes at Maruti Suzuki
51.	b)	Determining start and completion times for operations
52.	b)	Engage machines and operators efficiently
53.	b)	Routing
54.	b)	Time, investment, and idle workers
55.	c)	Dell
56.	b)	Analyze the flow of materials and information
57.	b)	Reduce inventory levels
58.	b)	By integrating quality checks at every production stage
59.	b)	Zara
60.	b)	Limiting the number of suppliers to a select few
61.	a)	Correcting existing problems and identifying new ones
62.	b)	Zara
63.	b)	Limiting the number of suppliers to a select few
64.	a)	Correcting existing problems and identifying new ones
65.	b)	Minimize equipment breakdowns

MODULE 5. PRODUCTIVITY MANAGEMENT AND QUALITY MANAGEMENT

Multiple Choice Questions (MCQs):

1. Productivity is a measure of:
 - a) How much input is required to achieve a given output
 - b) The number of employees in a company
 - c) The total revenue generated by a company
 - d) The market share of a company
2. Higher productivity helps a firm to:
 - a) Increase inventory levels
 - b) Beat competition
 - c) Reduce product quality
 - d) Decrease production efficiency
3. Productivity indices are useful for:
 - a) Marketing campaigns
 - b) Strategic, tactical, and planning purposes in management
 - c) Employee hiring processes
 - d) Customer service improvements
4. Which company uses productivity to maintain a competitive edge by improving vehicle production efficiency?
 - a) Apple
 - b) Tata Motors
 - c) Google
 - d) Amazon
5. How does productivity contribute to national prosperity?
 - a) By increasing the population size
 - b) By reducing the number of industries
 - c) By producing more with the same inputs at lower costs
 - d) By decreasing technological advancements
6. Higher productivity benefits labor by:
 - a) Increasing working hours
 - b) Reducing wages
 - c) Improving working conditions and salaries
 - d) Decreasing job security
7. What does continuous improvement in productivity lead to?
 - a) Higher costs
 - b) Increased waste
 - c) Innovative practices and new technologies
 - d) Decreased efficiency
8. In the context of productivity, what is the importance of planning in management?
 - a) Devising marketing strategies
 - b) Determining the most beneficial inputs for production
 - c) Increasing employee turnover



- d) Enhancing customer service
9. Which company uses productivity data to negotiate with trade unions and improve labor relations?
- Hindustan Unilever
 - Tesla
 - Facebook
 - Twitter
10. Optimal utilization of scarce resources involves:
- Reducing production
 - Utilizing available resources to the maximum extent
 - Increasing waste
 - Limiting technological advancements
11. Productivity is primarily measured by:
- Marketing costs
 - Output per unit of input
 - Employee satisfaction
 - Office layout
12. An increase in output per worker indicates:
- Higher marketing expenses
 - Improved labor productivity
 - Decreased production quality
 - Increased raw material costs
13. A decrease in man-hours per unit of output signifies:
- Reduced productivity
 - Improved labor efficiency
 - Increased production time
 - Decreased employee wages
14. The formula for productivity is:
- $P=I/O$
 - $P=O/I$
 - $P=(O \times I)/2$
 - $P=2 \times I \times O$
15. Measuring productivity helps in:
- Increasing resource wastage
 - Improving operational efficiency
 - Reducing product quality
 - Decreasing production output
16. The most widely used index of productivity is:
- Net profit
 - Man-hour output
 - Capital employed
 - Sales turnover
17. The formula for the productivity ratio of profit to capital employed is:
- Units of output/ Total man-hours
 - Net Profit/Capital employed
 - Added Value/Labour Costs

d) Value of output/Units of materials used

18. In cases where time standards cannot be set, which approach is more useful for measuring productivity?

- a) Net profit
- b) Sales turnover
- c) Added value
- d) Capital employed

19. The combined measure of productivity takes into account:

- a) Only labor costs
- b) Only capital assets
- c) Values of labor, capital, materials, and other inputs
- d) Only energy costs

20. Which company uses worker participation in decision-making to boost morale and productivity?

- a) Google
- b) Toyota
- c) Amazon
- d) Apple

21. What is a key benefit of improving communication services within a company?

- a) Increased marketing budget
- b) Enhanced productivity
- c) Reduced product quality
- d) Higher inventory levels

22. Which organization fosters mutual trust by implementing comprehensive training programs and incentives?

- a) Infosys
- b) Tesla
- c) Ford
- d) Samsung

23. How does Tesla boost efficiency in its production processes?

- a) By increasing physical labor
- b) By introducing advanced robotics and machinery
- c) By reducing product quality
- d) By increasing raw material costs

24. What is one of the technological aspects that can improve productivity?

- a) Decreasing employee engagement
- b) Implementing work, time, and motion studies
- c) Reducing communication channels
- d) Limiting equipment maintenance

25. Which company continuously improves its warehouse layouts for better material handling?

- a) Toyota
- b) Ford
- c) Amazon
- d) Nestle

26. How does General Electric minimize wastage and defective products?

- a) By increasing raw material costs

- b) By using advanced inspection methods
- c) By reducing employee training
- d) By increasing product complexity

27. Total Quality Management (TQM) involves everyone in an organization in a continual effort to:

- a) Increase profits
- b) Improve quality and achieve customer satisfaction
- c) Expand market share
- d) Develop new products

28. Which of the following is a basic concept in TQM?

- a) Decreasing production costs
- b) Employee involvement and empowerment
- c) Expanding business locations
- d) Increasing inventory levels

29. Continuous improvement (KAIZEN) in TQM focuses on:

- a) Reducing marketing expenses
- b) Enhancing processes and reducing waste
- c) Increasing employee salaries
- d) Limiting supplier interactions

30. Which company is known for focusing on both internal and external customers in its TQM approach?

- a) Microsoft
- b) Samsung
- c) OIBM
- d) Nestlé

31. Establishing performance measures for processes in TQM helps to:

- a) Increase production costs
- b) Improve efficiency and quality
- c) Limit employee participation
- d) Reduce customer satisfaction

32. What is a key philosophy of TQM?

- a) Maximizing profits at all costs
- b) Continuous improvement and customer satisfaction
- c) Expanding the product line
- d) Increasing supplier dependence

33. What is the focus of ISO 9000 certification?

- a) Environmental management
- b) Quality management
- c) Financial management
- d) Human resources management

34. ISO 14000 pertains to:

- a) Quality assurance
- b) Environmental management
- c) Production efficiency
- d) Customer service

35. Which ISO standard is concerned with ensuring products or services meet customer expectations?

- a) ISO 9000

- b) ISO 14000
- c) ISO 27001
- d) ISO 45001

36. ISO 14000 aims to:

- a) Increase production speed
- b) Minimize harmful environmental effects
- c) Improve financial performance
- d) Enhance customer satisfaction

37. The ISO 9001 model is used for quality assurance in:

- a) Production and installation
- b) Final inspection and test
- c) Design, production, installation, and servicing
- d) Environmental management

38. How many countries have adopted ISO 9000 as national standards?

- a) 60
- b) 70
- c) 80
- d) 90

39. Which company might implement ISO 14000 to reduce environmental impact?

- a) Google
- b) Tata Steel
- c) Netflix
- d) Facebook

40. ISO standards are related to an organization's:

- a) Products
- b) Services
- c) Processes
- d) Marketing strategies

Key:

1.	a)	How much input is required to achieve a given output
2.	b)	Beat competition
3.	b)	Strategic, tactical, and planning purposes in management
4.	b)	Tata Motors
5.	c)	By producing more with the same inputs at lower costs
6.	c)	Improving working conditions and salaries
7.	c)	Innovative practices and new technologies
8.	b)	Determining the most beneficial inputs for production
9.	a)	Hindustan Unilever
10.	b)	Utilizing available resources to the maximum extent
11.	b)	Output per unit of input
12.	b)	Improved labor productivity
13.	b)	Improved labor efficiency
14.	b)	$P=O/I$
15.	b)	Improving operational efficiency
16.	b)	Man-hour output

17.	b)	Net Profit/Capital employed
18.	c)	Added value
19.	c)	Values of labor, capital, materials, and other inputs
20.	b)	Toyota
21.	b)	Enhanced productivity
22.	a)	Infosys
23.	b)	By introducing advanced robotics and machinery
24.	b)	Implementing work, time, and motion studies
25.	c)	Amazon
26.	b)	By using advanced inspection methods
27.	b)	Improve quality and achieve customer satisfaction
28.	b)	Employee involvement and empowerment
29.	b)	Enhancing processes and reducing waste
30.	b)	Samsung
31.	b)	Improve efficiency and quality
32.	b)	Continuous improvement and customer satisfaction
33.	b)	Quality management
34.	b)	Environmental management
35.	a)	ISO 9000
36.	b)	Minimize harmful environmental effects
37.	c)	Minimize harmful environmental effects
38.	d)	90
39.	b)	Tata Steel
40.	c)	Processes

MODULE 6. PROJECT MANAGEMENT, MONITORING AND CONTROL

Multiple Choice Questions (MCQs):

1. What does an activity in project management represent?
 - a) A phase in marketing
 - b) A task consuming time and resources
 - c) A financial transaction
 - d) A software update
2. What is a start activity?
 - a) An activity with multiple successors
 - b) An activity with no predecessors
 - c) An activity with no duration
 - d) An activity completed last
3. What is a dummy activity?
 - a) A task that does not consume time or resources
 - b) A task that requires maximum resources
 - c) A task completed first
 - d) A task with the longest duration
4. The earliest event time (EET) is:
 - a) The latest time an event must occur
 - b) The earliest time an event can occur
 - c) The average time for event completion
 - d) The total project time
5. Free float represents:
 - a) The delay without affecting preceding activities
 - b) The total project delay
 - c) The delay without affecting succeeding activities
 - d) The overall project duration
6. The critical path is:
 - a) The shortest sequence of activities
 - b) The longest sequence of activities
 - c) The path with the least resources
 - d) The path with no significant events
7. Latest start time (LST) is calculated as:
 - a) $LFT - \text{Duration}$
 - b) $EFT + \text{Duration}$
 - c) $EST - \text{Duration}$
 - d) $LET + \text{Duration}$
8. What does the optimistic time estimate (to) represent?
 - a) Average time required for an activity
 - b) Shortest possible time for an activity
 - c) Longest possible time for an activity
 - d) Most frequently occurring time for an activity

9. Which time estimate denotes the maximum time required to complete an activity?

- a) Optimistic time estimate
- b) Most likely time estimate
- c) Pessimistic time estimate
- d) Expected time estimate

10. How is the expected time (T_e) calculated?

- a) $(t_o + t_p + 2t_m)/6$
- b) $(t_o + t_p + 4t_m)/6$
- c) $(t_o + 2t_p + t_m)/6$
- d) $(2t_o + t_p + 4t_m)/6$

11. What is a merge event in PERT?

- a) An event where more than one activity starts
- b) An event where more than one activity ends
- c) An event where no activity starts or ends
- d) An event with no dependencies

12. Which event marks the point where more than one activity starts?

- a) Tail event
- b) Merge event
- c) Head event
- d) Burst event

13. What is the standard deviation used for in PERT analysis?

- a) To calculate the exact project completion time
- b) To measure the variation in project completion time estimates
- c) To ignore uncertainties in project scheduling
- d) To determine resource allocation

14. In PERT, the most likely time (t_m) is:

- a) The shortest possible time for an activity
- b) The time an activity will most frequently take
- c) The maximum time required for an activity
- d) The calculated average time for an activity

15. What is the main focus of CPM?

- a) Time
- b) Cost
- c) Event
- d) Time-cost trade-off

16. Which project management tool uses probabilistic time estimates?

- a) CPM
- b) PERT
- c) Gantt Chart
- d) Microsoft Project

17. PERT is more suitable for:

- a) Construction projects
- b) Manufacturing projects
- c) Repetitive projects
- d) New projects with high uncertainty

18. In CPM, the time estimates are:

- a) Probabilistic
- b) Deterministic
- c) Variable
- d) None of the above

19. Microsoft Project helps in:

- a) Painting buildings
- b) Developing schedules and assigning resources
- c) Writing code
- d) Conducting market research

20. PERT focuses on:

- a) Milestones and events
- b) Market trends
- c) Employee satisfaction
- d) Profit margins

Key:

1.	b)	A task consuming time and resources
2.	b)	An activity with no predecessors
3.	a)	A task that does not consume time or resources
4.	b)	The earliest time an event can occur
5.	c)	The delay without affecting succeeding activities
6.	b)	The longest sequence of activities
7.	a)	LFT - Duration
8.	b)	Shortest possible time for an activity
9.	c)	Pessimistic time estimate
10.	b)	$(t_o + t_p + 4t_m)/6$
11.	b)	An event where more than one activity ends
12.	d)	Burst event
13.	b)	To measure the variation in project completion time estimates
14.	b)	The time an activity will most frequently take
15.	d)	Time-cost trade-off
16.	b)	PERT
17.	d)	New projects with high uncertainty
18.	b)	Deterministic
19.	b)	Developing schedules and assigning resources
20.	a)	Milestones and events

MODULE 7. ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

Multiple Choice Questions (MCQs):

1. Which type of maintenance is performed only after equipment has failed?
 - a) Preventive Maintenance
 - b) Routine Maintenance
 - c) Break Down Maintenance
 - d) Predictive Maintenance
2. What is the primary goal of preventive maintenance?
 - a) To fix equipment after it fails
 - b) To conduct repairs based on predictions
 - c) To perform regular tasks to prevent failure
 - d) To monitor equipment continuously
3. Which maintenance type uses data analytics to predict equipment failure?
 - a) Routine Maintenance
 - b) Break Down Maintenance
 - c) Preventive Maintenance
 - d) Predictive Maintenance
4. What is a key advantage of routine maintenance?
 - a) High initial investment
 - b) Minimizes major problems by addressing minor issues
 - c) Requires no resource allocation
 - d) Involves high-cost tasks
5. In which industry is preventive maintenance particularly critical?
 - a) Software development
 - b) Aviation
 - c) Retail
 - d) Marketing
6. What is a potential drawback of predictive maintenance?
 - a) It does not prevent equipment failure
 - b) High initial cost for monitoring technologies
 - c) Requires no skilled personnel
 - d) Performed only after equipment breaks down
7. Which type of spare part is kept as an "insurance" against equipment failure?
 - a) Regular Spare
 - b) Insurance Spare
 - c) Capital Spare
 - d) Rotable Spare
8. What is a characteristic of capital spares?
 - a) Low cost and high usage
 - b) Critical for equipment operation and high stock-out cost
 - c) Frequently used and easily replaced
 - d) Periodically overhauled and reused

9. Rotable spares are typically:
 - a) Used frequently and discarded after use
 - b) Used rarely and vital for operation
 - c) Changed out periodically for repair or overhaul
 - d) Kept as an insurance against failures
10. Bolts, nuts, and seals in a manufacturing plant are examples of:
 - a) Capital Spares
 - b) Insurance Spares
 - c) Regular Spares
 - d) Rotable Spares
11. What type of spare part would a spare turbine blade in a power plant be considered?
 - a) Regular Spare
 - b) Insurance Spare
 - c) Capital Spare
 - d) Rotable Spare
12. Which type of spare part is frequently used in maintenance and has a lower per-unit cost?
 - a) Capital Spare
 - b) Rotable Spare
 - c) Regular Spare
 - d) Insurance Spare
13. What is the key principle behind preventive maintenance?
 - a) Repair after failure
 - b) Prevention is better than cure
 - c) Replace only when broken
 - d) Ignore minor faults
14. Which of the following is NOT an advantage of preventive maintenance?
 - a) Increased equipment life
 - b) Greater worker safety
 - c) Higher reserve equipment requirement
 - d) Better product quality
15. What are Regular Spares primarily used for?
 - a) Emergency replacements
 - b) Routine maintenance
 - c) Capital investment
 - d) Long-term storage
16. Which type of spare part is refurbished and reused?
 - a) Insurance Spare
 - b) Regular Spare
 - c) Rotable Spare
 - d) Capital Spare
17. Which spare part type is usually purchased during initial equipment procurement?
 - a) Regular Spare
 - b) Rotable Spare
 - c) Insurance Spare
 - d) Capital Spare

18. What is a key characteristic of Regular Spares?
 - a) High cost and rare usage
 - b) Long lead time
 - c) Frequently replaced and low cost
 - d) Used only in emergencies
19. Which of the following is an example of a Rotable Spare in a centrifugal pump?
 - a) Gasket
 - b) Motor bearings
 - c) Nuts and bolts
 - d) Pump casing
20. Capital spares are typically associated with:
 - a) Consumables
 - b) High-value structural components
 - c) Lubricants
 - d) Safety gear
21. What makes Insurance Spares strategically important?
 - a) They are used daily
 - b) They are easy to procure
 - c) They prevent costly production losses
 - d) They are part of routine servicing
22. Which spare part type has the longest lead time and highest cost?
 - a) Regular Spare
 - b) Rotable Spare
 - c) Capital Spare
 - d) Insurance Spare
23. Which spare part type is least likely to be used frequently but must be available?
 - a) Regular Spare
 - b) Rotable Spare
 - c) Insurance Spare
 - d) Capital Spare

Key:

1.	c)	Break Down Maintenance
2.	c)	To perform regular tasks to prevent failure
3.	d)	Predictive Maintenance
4.	b)	Minimizes major problems by addressing minor issues
5.	b)	Aviation
6.	b)	High initial cost for monitoring technologies
7.	b)	Insurance Spare
8.	b)	Critical for equipment operation and high stock-out cost
9.	c)	Changed out periodically for repair or overhaul
10.	c)	Regular Spares
11.	b)	Insurance Spare
12.	c)	Regular Spare
13.	b)	Prevention is better than cure
14.	c)	Higher reserve equipment requirement
15.	b)	Routine maintenance
16.	c)	Rotable Spare

17.	c)	Critical equipment with high downtime cost
18.	d)	Capital Spare
19.	c)	Frequently replaced and low cost
20.	b)	Motor bearings
21.	b)	High-value structural components
22.	c)	Prevent costly production losses
23.	c)	Capital Spare
24.	c)	Insurance Spare



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